PHD

An investigation of the effects of government incentives to implement the car’s green technology: a supply chain management perspective

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Abstract

This research project investigates the influence of government incentive on supply chain behaviour from an operations research perspective, providing insights into government green policy making and supply chain management. In the car industry, government green incentive is used to facilitate corporate investment in green technology in the supply chain by financial support chain supply parties. The existing literature has limited understanding of how government ought to provide incentives efficiently and how the supply chain should respond to these incentives. This project is first to analyse the decision making of all the participating parties in the government incentive project. It provides suggestions for government policy makers and illustrates managerial implications for supply chain operational strategies.

This research study is divided into three parts, Preliminary Study 1, Preliminary Study 2 and Main Study 3. Preliminary Study 1 and Preliminary Study 2 constructed the initial incentive model, based on which a comprehensive incentive model is built and analysed in Main Study 3. Preliminary Study 1 confirmed the influence of government incentive on supply chain decision making. A two-stage game theory model is established to formulate supply chain behaviour on the basis of a mathematical modelling technique. Preliminary Study 2 is focused on practical information collection by adopting semi-structured interview. 11 interviews were conducted in the car industry including suppliers and manufacturers in Taiwan. The collected data is used to provide the necessary information for the establishment of the simulation model in Main Study 3. All the components and assumptions of the

incentive model are verified by the implications of Preliminary Study 2. Finally, in Main study 3, a multiple period optimisation-simulation incentive model is built to simulate the decision-making process of incentive projects.

The findings of this project indicate that government incentives have a positive effect on green technology improvements in the supply chain. Four incentive strategies have been proposed in response to different market scenarios of the government's green policy making. The High incentive strategy leads to the best green technology improvement in the supply chain. However, when the government has limited budget for green incentives, it is suggested that the Manufacturer Focus strategy or Supplier Focus strategy is implemented instead of the incentives being equally distributed in the supply chain. It was found overall, that the best strategy of incentive policy is associated with the cost of green technology in the supply chain and the green car market size.

Further findings indicated that government incentives also indirectly affect supply chain pricing strategies. It was found that as incentives increase, green technology level rises, and the supply chain increases its pricing to respond to the costs. Based on this finding, this study suggests that the government should provide incentives to the consumers directly when the economy depresses and consumers' greenness sensitivity is low. For the supply chain, and based on different market scenarios, the implications of optimal green technology and pricing decision are proposed. Finally, it is suggested that supply chain parties should consider the incentive circumstances of their upstream and downstream in order to optimise their own profit when the government provides green incentive to the supply chain.

Table of Contents

Table of Figures

Table of Tables

Chapter 1: Introduction

1.1 Introduction to the research

After electricity production, human transportation activities have the second largest impact on the environment (US EPA, 2016). Carbon dioxide emission produced by transportation accounted for up to 26% of the overall greenhouse gas (GHG hereafter) emission up to 2014. In response to this, a variety of international environment agreements, such as the Kyoto Protocol and the EUETS (European Union Emission Trading Scheme, EUETS), have emerged over the past few years, and governments across the world have been appealed to join them. In addition, as consumers' environmental awareness rises, governments are also urged to address the issue of GHG emission. Maximising emission reduction becoming governments' objective (Cohen et al., 2015) leads gradually to the introduction of various government green interventions on green products.

A green product is defined as an environmentally friendly or sustainable product (Cao et al., 2013), which produces less emission, pollutions and waste and can help with environmental protection (Ottman et al., 2016). The concept of "green" in this research is interpreted as "environmentally friendly" that a product produces less carbon emissions from the product use. The green product indicates the "green use" of the product and product's greenness is connected by the green design of the product. Because green technology adoption can effectively increase the product's energy efficiency, the government aims to reduce the GHG emissions by promoting green products. To reduce emissions, besides transportation, the car industry (automotive sector) is widely regarded as the main source of GHG emission due to the large fuel consumption of its products (US EPA, 2016). Thus, in many countries, the car industry is targeted as a key point to reduce GHG emission (Van Soest, 2005; Barari et al., 2012) because of the potential of green car adoption. Within the car industry, it is the adoption of green vehicles that is believed to be an effective way to reduce GHG emission by transportation (Mak et al., 2013; Gnann et al., 2015). Therefore, in many countries, government green policies have been designed to facilitate this agenda. In the U.S., the government is seen to implement green policies to stimulate the manufacturing of greener cars, and thus reduce fuel consumption (Krutilla & Graham, 2012). In the meantime, they also implemented The Energy Policy Act of 2005 and subsidies hybrid car buyers through the income tax system. In addition to the U.S., similar green policies and government incentives can also be found in many countries such as U.K. (Plug-in vehicle grant), China (Technology innovation funding), France (Bonus-malus system), Germany (Electrical vehicle incentive program), Japan (Subsidies to purchasers of electrical vehicles), and Taiwan (Research funding for green technology development). To reduce emissions, it is important for the government to drive green technology adoption in the car industry by effectively allocating incentives (Goulder & Mathai, 2000). It is evident that governments are stimulating consumers' demand for green vehicles and facilitating the adoption of green technology by supply chain parties in an attempt to effectively reduce GHG emission in the car industry. Thus, the car industry (automotive sector) is selected as the research context in this research to investigate the influence of government incentives on supply chain behaviour regarding green technology adoption.

Among government green interventions, many scholars recognise incentive as an effective approach to control GHG emission (Chappin et al., 2009; Coria, 2009; Dowson et al., 2012; Fischer et al., 2003; Fischer & Newell, 2008; Jaffe et al., 2005; Requate & Unold, 2003; Van Soest, 2005). In the car industry, government green incentive is used to facilitate the corporate investment in green technology in the supply chain by sharing the financial burden and making it significantly more affordable than before. Supply chain parties thus are becoming more willing to invest in green technology innovation.

There are two reasons for car companies' investment in green technology. First, car companies invest substantially in the development and adoption of green technology in an attempt to improve fuel efficiency in their products and manufacturing process (Xu et al., 2013). Second, car companies seek to develop green products in order to cope with the ever-rising environmental awareness of consumers (Barari et al., 2012; Flammer, 2015). Because government incentives indirectly reduce the overall cost of the green technology investment, these are proven to have a significant impact on green technology adoption in hybrid vehicles (Diamond, 2009). The policies of green incentive in U.S. (Diamond, 2009), Netherland (Chappin et al., 2009) and Norway (Mersky et al., 2016) have also demonstrated a positive impact on green technology development in their car industries. Technology development is one of the production decisions made in supply chain management. Since the decision on green technology development can be influenced by government incentives, this suggests that supply chain behaviour can also be influenced by government incentives and expectedly towards a more environmentally friendly direction.

This research considers only government incentives from an economic perspective. Government disincentives such as environmental regulations and emission allowance from a regulatory perspective are not considered. As this research focuses on the influence of the government's intervention to green technology adoption, disincentives cannot significantly affect the green technology adoption in the supply chain directly. For example, regulatory policies do not result in any difference in green technology change for different car models, and they concern more with emissions produced during production process instead of emissions produced from the use of the product. Therefore, disincentive policies only manage emissions by reducing the total quantity of production and the emission and waste in the production process. Thus, this research only focuses on government incentives which have a significant influence on the supply chain green technology adoption and development. The disincentives are not considered in this research which is addressed as a research limitation in Section 7.4.3.

Practical Motivation

In order to increase the efficiency of government incentives in driving green technology development and adoption in the supply chain, it is important to understand both the ways in which incentive should be given and the corresponding decision making in the supply chain. Existing literature tends to investigate this issue only from the perspective of the government (Chappin et al., 2009; Cohen et al., 2015; Coria, 2009; Diamond, 2009; Dowson et al., 2012; Gallagher & Muehlegger, 2011; Jena et al., 2018; Zhang & Wang, 2017) or only from the perspective of supply chain (Fischer et al., 2003; Goulder & Mathai, 2000; Krass et al., 2013), thus lacks an understanding from a perspective involving all participated parties.. To address this gap, this research does not only examine the influence of government incentives on the development and adoption of green technology from the perspective of supply chain management but also considers the government's perspective, providing managerial insights for both operational decision maker in supply chain and green policy maker in government.

1.2 Contribution to the existing literature

Green supply chain or sustainable supply chain link the sustainability to traditional supply chain management (Ashby et al., 2012). The key concepts in green supply chain management include green strategy, green design, green purchasing, manufacturing process, logistics, marketing, and recycling (Zhu & Zou, 2011). It was indicated that government plays an important role in implementing green policies which change the supply chain behaviour when pursuing sustainability in supply chain management (Zhao et al., 2012; Sheu & Chen, 2012; Chung et al., 2013). Researchers have been investigating sustainability in supply chain management in various contexts, such as operation strategy (Lam et al., 2013; Swami & Shah, 2013), government incentive (Georgiadis, 2004; Sheu et al., 2005; Webster & Mitra, 2008; Jin et al., 2011; Sheu & Chen, 2012), and supply chain economics modeling (Cabral et al., 2012, Sarkis, 2003; Zhu et al., 2008; Mirhedayatian et al., 2013; Zhu, 2013).

Different approaches and theories have been employed to analyse supply chain management from operational research perspective, such as fuzzy theory (Tsai & Huang, 2009; Wang et al., 2012; Wang, 2013), and game theory (Jin et al., 2011; Zhao et al., 2012; Sheu & Chen, 2012; Zhang & Liu, 2013). Specifically, issues concerning supply chain incentives have been discussed extensively in the literature. For instance, Webster and Mitra (2008) and Jin (2001) looked at green product promotion by government incentives while Chen and Sheu (2009) investigated supply chain pricing problems with government intervention. Zhao (2012) examined the manufacturer's decision making under the consideration of the government's environmental penalty. Despite the great quantity of the research in the area of supply chain management and operational research, discussions have usually revolved around optimisation problems for single supply chain party (Jin, 2011; Sheu & Chen, 2012). However, governments provide incentives to multiple supply chain parties, and the product's greenness is determined by multiple participated supply chain parties rather than a single party. How the whole supply chain parties' behaviour may have responded to government incentives is still unknown and how government incentives may have affected the supply chain green technology adoption is not clear either, which suggests a theoretical gap in the extant literature. Hence, the present research focuses on investigating supply chain behaviour, which is influenced by government interventions from an operational research perspective and contributes to the supply chain management literature.

In order to identify incentive influence, a theory-based government incentive model will be built in Preliminary Study 1. It is followed by the qualitative empirical research in Preliminary Study 2 which provides practical data to verify the theoretical model and produces the foundation of the simulation model in Main study 3. Eventually, a comprehensive simulation model is built to explore the supply chain behaviour and government incentive strategy. In addition to the theoretical contributions to the extant literature, this research also aims to provide practical implications to industrial practitioners and suggestions for policy management for governments' green policy decision makers.

Green technology is also called clean technology (Hall & Helmers, 2013) or emission-reducing technology (Krass et al., 2013). Green technology adoption indicates the level of green technology applied in car design, and it affects the carbon emissions produced from car use. In the car industry, the adoption of green technology is a technology innovation for green cars (Daziano & Bolduc, 2013). It has been found that in the car industry, higher gasoline prices can increase green technology adoption (Diamond, 2009) and that gasoline price is positively related to hybrid car sales but only for high-level green technology cars (Gallagher & Muehlegger, 2011). Market consumers prefer to buy a green car with higher green technology (Pickett-Baker & Ozaki, 2008) and with lower emissions (Daziano & Bolduc, 2013). Previous studies have identified the significant relationship between green technology adoption and green car sales, indicating the importance of green technology when the government aims to increase market sales and thus reduce emissions from car use. Thus, promoting green technology adoption is the main focus when investigating governments' green policy management of emission reduction in the car industry.

Secondly, the uncertainty of green preference regarding consumer demand is considered. The impact of market uncertainty on green technology adoption was demonstrated by Cohen et al. (2015), who took a random factor into a price dependent demand function to investigate the influence of demand uncertainty on manufacturing industry response. However, for green products, not only the price (Wu et al., 2009) but also green preference can affect the demand (Pickett-Baker & Ozaki, 2008; Lee et al., 2013). For example, when the price of gasoline increases, consumers show more willingness to buy green vehicles than when it is low. In addition, consumers are more sensitive to the product's greenness when they have a firm intention to behave in an environmentally friendly way. Thus, green preference is uncertain because it is dependent on consumers' perception. Although price sensitivity was used as a variable in the demand function before Abad (1994), no attempt has been made to consider both price and consumer green preference as uncertainties when managing green technology adoption in the supply chain. By considering the uncertainty of green preference in the hybrid vehicles market, the supply chain practice can be formulated more closely than a pure price dependent demand. The present project aims to study how supply chain management behaviour is influenced by government incentives considering the uncertainty of price sensitivity and consumer green preference with the market demand.

In summary, this research enquiry first investigates the influence of government green incentive to supply chain behaviour (Preliminary Study 1 and Preliminary Study 2); and second, it illustrates supply chain optimal decision making by simulating the behaviour and interaction between the government and supply chain parties (Main Study 3).

1.3 Research questions and objectives

The present study aims to investigate the influence of government incentive on supply chain behaviour by looking at the response of the supply chain and the market affected by the incentives, and to provide strategic insights for government incentives and managerial suggestions for supply chain decision makers. Preliminary Study 1 proposes a mathematical game model to investigate the influence of incentives supply chain and green product market. The influence of the incentive is focused on the evaluation of 3P (people, planet, profit). To examine the influence of the incentive, Preliminary Study 1 includes the supplier and the manufacturer only to discuss the impact of the incentive in the supply chain. Preliminary Study 2 aims to explore the industry information to develop a practical based incentive model by semi-structured interviews. To build an incentive model which takes Preliminary Study 1 and Preliminary Study 2 as a foundation, the simulation method is chosen to apply in Main Study 3. Simulation modelling is appropriate to analyse the decision-making process in the supply chain because the theoretical foundation of this type of model has a better flexibility to formulate an economic model (Page, 2005) and simulation modelling is a way to help with relaxing the assumptions in Preliminary Study 1. Main Study 3 adopts a simulation approach to analyse the decision-making process of the government incentive project, it identifies the influence of the government incentive on supply chain behaviour from a supply chain management perspective.

Issues concerning the influence of incentives on supply chain operations have been discussed extensively in the literature, such as government green product promotion

(Webster and Mitra, 2008; Jin, 2001), the influence on supply chain pricing (Chen & Sheu, 2009) addressing this issue from manufacturer's perspective only (Fischer et al., 2003; Goulder & Mathai, 2000; Krass et al., 2013; Zhao, 2012). Of the great quantity of research in this area, numerous discussions have revolved around optimal decision-making problems (Jin, 2011; Sheu and Chen, 2012). How the whole supply chain behaviour may have responded to the government incentives are still unknown, and this suggests a theoretical gap in the extant literature. To fill this literature gap, the present study focuses on investigating supply chain behaviour, which is influenced by government interventions. The project seeks to answer hitherto unresolved research questions and thus add new knowledge to the literature. Each sub-study question responds to the research questions and they are also interrelated to each other.

Main Research Question:

How do government incentives affect supply chain behaviours?

Sub-research question 1:

How do government green incentives affect the supply chain's green technology decision making?

Sub-research question 2:

How do government green incentives affect supply chain's pricing?

To answer the research questions, Preliminary Study 1 and Preliminary Study 2 firstly investigate the influence of government incentives based on a game theory model and the analysis of qualitative data collected in the car industry. Main Study 3 answers the research question based on a comprehensive simulation-based incentive model.

The literature indicates that government policy influences the operating strategy of the supply chain (Zhao et al., 2012; Sheu & Chen, 2012), and government interventions can also lead to green supply chains integration (Sheu et al., 2005). To achieve the integration in the green supply chain, the government provides incentives to supply chain, which can help to overcome the conflicts of operational goals among supply chain parties (Sheu et al., 2005). An example of the integration could be driven by the incentives is the integration of logistics flows. The goals of the supply chain parties in reverse-logistics chain are different from the manufacturer's in the forward supply chain. This is because the recycling in the reverse logistics will increase the manufacturer's cost. Government incentives can thus be used to cover the cost of recycling for the manufacturer to achieve the integration of the logistics flows. In addition, government subsidies can help promote green production in the supply chain and increase the product market demand (Neto et al., 2008; Webster & Mitra, 2008; Jin, 2011). Thus, there is strong evidence to indicate that government action has a significant effect on green products. Thus, Preliminary Study 1 aims to address the findings from the above literature as well as evaluate the government's influence through 3P that is, profit (supply chain), planet (environment) and people (market).

The objective of Preliminary Study 1: Examining the influence of government incentive by conducting a mathematical game modelling approach.

In previous studies, only limited parties have been selected to research into the incentive model. For example, Sheu and Chan (2012) conducted a three-stage incentive model based on game theory (two supply chain parties), and Webster and Mitra (2008) proposed an incentive game model that included only manufacturer and remanufacturer. Zhang and Liu (2013) also have built four incentive models based on a different structure of the cooperated game. However, practical operations are more complex than a two or three stages game model, and it is expected to have more parties in the incentive network. Hence, Preliminary Study 2 attempts to identify the decision-making process in the incentive projects which will be used as the foundation for the Main Study 3.

The objective of Preliminary Study 2: Verifying the theoretical incentive model and constructing the component/framework of a comprehensive green product incentive model based on qualitative data.

The research project aims to confirm the effect of government incentive and provide practical managerial implication through model analysis. Although government incentive strategy has been discussed in the literature (Chen & Sheu, 2009; Jin, 2011; Sheu & Chen, 2012), it seems that none of the government incentive strategies was suggested based on practical information but on theoretical mathematical models. For this reason, the research question of Main Study 3 adopts the initial incentive model in Preliminary Study 1 as its foundation and applies the results from Preliminary Study 2 to build a comprehensive simulation model.

The objective of Main Study 3: Investigating the influence of government incentives, providing efficient green product incentive strategy for governments and optimal operation strategy for supply chain managers by simulating the decision-making process in the incentive project.

Eventually, the findings of the three sub-studies can provide governments and green product providers suggestions for making incentive, pricing, and green technology decisions. Also, the study contributes novel knowledge to the literature of operation management and economics by establishing an incentive model based on an optimisation-simulation modelling approach.

1.4 Structure of the research

This project aims to investigate the influence of government incentive on supply chain behaviour by building a green product incentive model through several interrelated studies. There are three parts in this research enquiry (Preliminary Study 1, Preliminary Study 2 and Main Study 3); first, a mathematical game incentive model is used to investigate the incentive influence on supply chain and market. In Preliminary Study 1, the government, the manufacturer and the supplier will be considered in the model. Next, the objective of the Preliminary Study 2 is focused on practical information collection by adopting the semi-structured interview to enhance and adjust the modelling choices/assumptions of the incentive model in Preliminary Study 1. To investigate the influence of the government incentives on supply chain behaviour, Main Study 3 combines the foundation of the model from Preliminary Study 1 and Preliminary Study 2. In the Main Study 3, a comprehensive incentive model is created based on of a simulation approach that contains the government, supply chain parties and consumers. An optimisation-simulation approach is put into use to analyse the decision-making process in the incentive model and to understand the supply chain behaviour changed by the government incentives. The objectives, the applied theories and methods for the three sub-studies are presented in Table 1.

Chapter 1 of this project contains the introduction. It is followed by a literature review of related topics in Chapter 2. An overview of the methodology is included in Chapter 3. Next, Chapter 4 and 5 comprise the initial investigation of the influence of government incentives, Preliminary Study 1 and Preliminary Study 2. Chapter 6 contains the Main Study 3 of this project, a simulation modelling research of the government incentives. The conclusion and discussion of the results are presented in Chapter 7. References and research appendix are included at the end of this thesis.

Table 1 - The structure of the research proposal

	Objective	Method	Method and research design
Preliminary Study 1	Investigating the influences of the government incentives on the supply chain, market demand and the environment.	Game theory model	Given an incentive rate to solving a mathematical game model to gain optimal strategies of the supply chain
Preliminary Study 2	Developing a comprehensive and thorough incentive model that includes various parties based on industrial information.	Semi-structured interview	Qualitative research: Gathering practical information by semi-structured interviews from managers in the car industry to establish the foundation of the simulation model in Main Study 3
Main Study 3	Constructing a simulation model according to the research framework of Study 2, analysing interactions among government, supply chain and consumers, providing insights for decision makers of supply chain and government.	Optimisation-simulation model	Building a simulation model of the decision-making process in the government incentive project. Combining the game theory model in Preliminary Study 1 and the qualitative research in Preliminary Study 2 to build a comprehensive incentive model.

Chapter 2: Literature Review

2.1 Introduction

This research project aims to investigate the influence of government incentives on supply chain behaviour from a perspective of supply chain management. A comprehensive literature review of existing literature is presented in this chapter. A systematic literature review is an effective way to capture a general knowledge of current literature, thus the systematic literature review as suggested by Bryman and Bell (2007) is used. Before the systematic literature review, my PhD supervisors, who have knowledge and research experiences in the research area, were invited to be review panel. Professional suggestions regarding the literature review were given in regular meetings.

Based on the discussion with the review panel, the objectives of the literature review were summarised as follows:

1. To understand the influence of environmental issues on government policy and its indirect effect on the supply chain behaviour.
2. To obtain an understanding of the development of sustainability in supply chain, and how it relates to green technology and green product in the supply chain.
3. To identify government incentives for emissions reduction in the supply chain.
4. To identify the gaps in the literature that this research can address and make a contribution to existing literature.

Following the discussion with the review panel, several topics in the literature were identified to be reviewed. “The influence of the increasing awareness of environmental issues on government policy”, “The influences of environmental issues and government policy on supply chain behaviour”, “Sustainability in supply chain management”, “Green technology and Green Products”, “Sustainable/green Supply Chain Management”; “Government Intervention in sustainable supply chain”; “Automotive sector and its green practice”. In addition, the review of the methodologies applied in supply chain management is also demonstrated in this section.

Based on the identified review objectives and review topics, “government policy”, “government incentives”, “supply chain management” were selected as the initial keywords for literature search. Other keywords, which are relevant to the issues in question, were also considered. They are presented in Table 2.

Due to that this research aims to take a perspective of supply chain management literature that has been selected was mainly from the area of “*Operations Management*”, “*Operations Research*”, and specifically on sustainable supply chain management. In addition, literature from other related fields, including management and accounting, Economics, Econometrics and Finance, Engineering, Mathematics, Computer science, was also included. Different combinations of the keywords were used in the literature search. Three main databases were used to search the literature: SCOPUS, ScienceDirect and EBSCO. Searching target included books, journal articles, research working papers, government public reports, and conference publications. The criteria are presented in Table 2.

Table 2 - Searching criteria for literature

Keywords applied (And/Or)		Keywords applied (And/Or)
Incentives		Supply chain
Subsidy		Supply chain management
Green tax		Sustainable supply chain
Carbon tax		Green supply chain
Green policy		Green supply chain management
Green regulation		Sustainable supply chain management
Sustainability	**AND**	Manufacturer
Emissions		Supplier
Greenhouse gas		Green technology
Government intervention		Environmentally friendly technology
Semi-structured interview		Green products
Simulation		Market demand
Optimisation-Simulation		Pricing decision
Game theory		Green technology adoption
Car industry		
Automobile Industry		

Key findings

Based on the above literature search, several topics are identified, government policy in the supply chain, the green issues in the supply chain, the development of green technology and green product. The result of the search has achieved the goals stated at the beginning of the section. Key findings are summarised as follows:

1. The influence of the environmental issues on government policy has been discussed widely in the literature, and it also drives the adoption of green technology in the supply chain.
2. The positive effect of government incentives on green technology development in the supply chain is suggested in the literature, which shows the connection between environmental issues, government green policy, and supply chain behaviour.
3. The traditional supply chain has adopted greener practice due to the increasing awareness of environmental issues. Today, supply chain parties are more willing to participate in green supply chain activities as a result of government policy and market trend.
4. Green supply chain management and sustainable supply chain management have gained much attention recently, which results in the development of green product and the adoption of green technology production in the supply chain, including car industry.
5. Although previous studies have investigated the influence of government incentives on green technology in supply chain and identified potential implications, gaps, in terms of how supply chain decision maker should respond to government green policy and how government should provide the

incentives, still exist in the literature. Addressing these gaps will make both theoretical and practical contributions to the literature, thus this research aims to address these research gaps from operations research perspective.

The literature review of this thesis is structured as follows. Firstly, the influence of the increasing awareness of environmental issues on government policy and supply chain behaviour will be reviewed in sections 2.2 and 2.3. Secondly, the sustainability in the supply chain, green technology and the development of the green products in the sustainable supply chain will be discussed in sections 2.4, 2.5 and 2.6. Thirdly, government green intervention, the automotive sector and its green practice will be reviewed in sections 2.7 and 2.8. Finally, section 2.9 concludes this chapter.

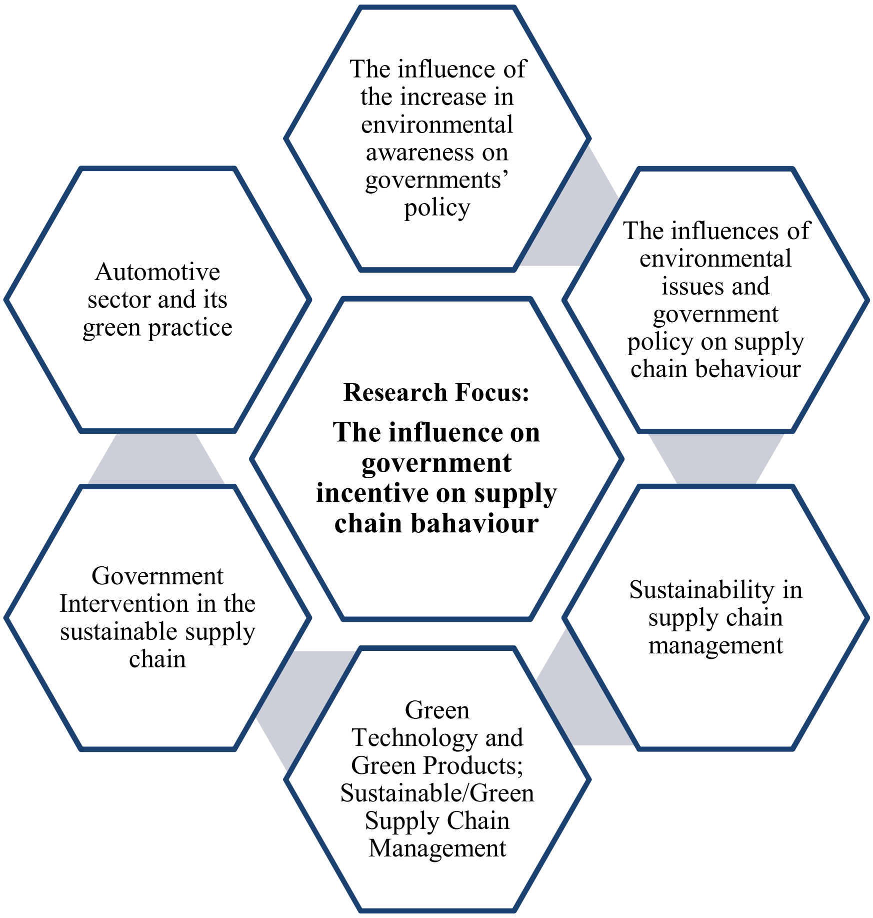


Figure 1 - The framework of literature review

2.2 The influence of the increase in environmental awareness on governments' policy

The WTO (world trade organisation) announced that sustainable development and environmental protection are the primary objectives in the management of global trades (World Trade Organisation, 2013). Environmental sustainability has become a concern among businesses because of pressing environmental issues, such as global warming (Xu et al., 2013). As a result of the globalisation of businesses and the increase in consumption, stakeholders and national legislations today expect business managers to take not only economics but also environmental impacts into consideration (Dahlsrud, 2008; Malladi & Sowlati, 2018). The excessive consumption of resources, the consequential waste, and environmental pollution have become a concern as serious as economic growth. Resource crisis has also become a worldwide threat in recent years. The natural disaster was considered as extreme events which are caused by the scarcity of environmental resources (Bhavnani, 2006). There are fears that dramatic climate changes will increase frequency of extreme events (Tompkins & Adger, 2004). To solve this problem, a country's development should not only concentrate on the economic but also environmental factors. Governments' green intervention is thus driven by the pressure of environmental protection, and previous research has identified green policy as an effective approach to control GHG emission (Chappin et al., 2009; Coria, 2009; Dowson et al., 2012). It is necessary for governments to effectively implement green policies to drive/lead industries to become more environmentally friendly.

Both developing and developed countries have conducted the green policy. For example, China has adopted *The Green Fence Policy* in 2013 in order to address environmental issues in the Chinese market. Similarly, the UK government proposed the *UK Climate Change Act 2008* which requires the government to publish carbon budget every five years to achieve the government's target of emission reduction by 2050 (Hitchcock, 2012). Due to human activities since the industrial revolution in the 18th century, the emission has become a significant issue (Sarkis et al., 2011). Governments have started to adopt green policies in order to prevent industries and society from producing too much emission. For example, the green policy in the United States focuses on reducing oil consumption, and thus the production of environmentally friendly cars is encouraged (Krutilla & Graham, 2012). Another example in the UK is that the government adopted green policies to manage the environmental emission caused by the industrial revolution. In the year of 2013, UK was facing an energy crisis with record-breaking hikes in energy bills and the threat of blackouts by 2015. In the same year, UK government announced the Green Deal Cash-back Incentive Scheme, which assigns incentives to consumers based on their improvement in energy saving, in an attempt to promote environmentally friendly behaviours in the country. Many other governments in developed countries also implement strict environmental regulations in order to force industries to change their operation strategies and lower emissions from fossil fuel consumption (Xu et al., 2013). As the government is expected to be responsible for environmental protection, green policies are conducted in most of the countries in order to lead the industry and society to be more environmentally friendly. It is in this context that this research project aims to investigate the influence of government green policy on supply chain behaviour.

2.3 The influences of environmental issues and government policy on supply chain behaviour

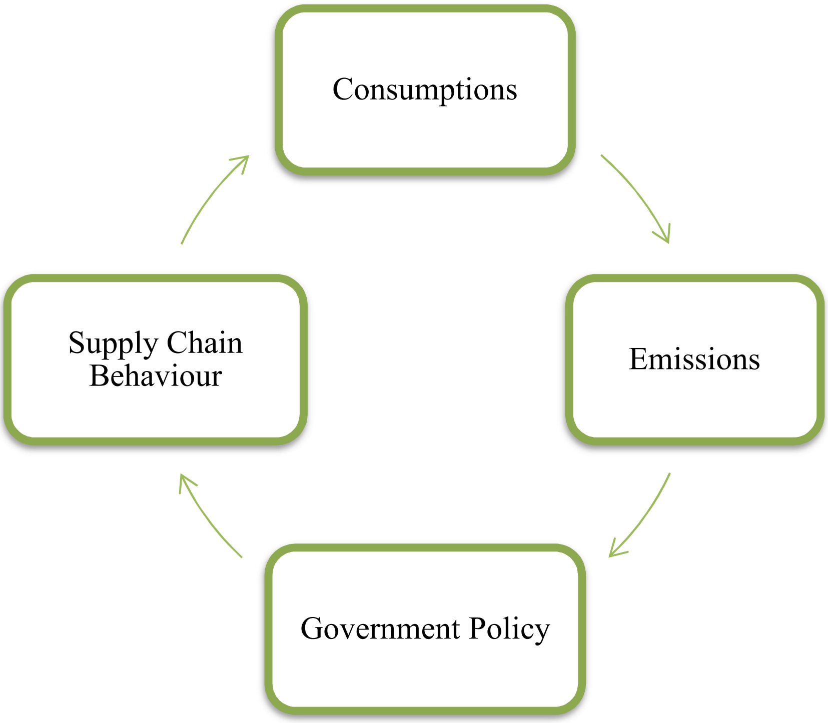


Figure 2 - The influences of environmental issues and government policy on supply chain behaviour (arrows in the figure indicate the influence of one concept to another)

Consumptions, Emissions and Government policy

Figure 2 shows the influence of one concept on another. The topics of consumptions, emissions, government policy and supply chain behaviour are directly or indirectly connected, as shown in Figure 2. Consumption is the main issue related to carbon emissions. The global consumption database from The World Bank states that consumption, including private consumption and general government consumption, is increasing globally (The World Bank, 2019). In China, it has risen dramatically by 87% in four years, from $2,193 billion in 2008 to $4,112 billion in 2012. In the US, it was \$12.4 trillion in 2008 and then went up to \$13.3 trillion in 2011. This great amount of consumption is leading to ruinous emissions, causing a trade-off between consumption and emissions (Clarke & Reed, 1994). Environmental regulations are made to prevent the emissions which are caused by the huge consumption of energy. The Committee on Trade and Environment (CTE) in the WTO conducts Technical Barriers to Trade Agreement to the participated member countries so that governments can share information about the ways in which the green actions/regulation they are adopting has significant influences on trading behaviour and production activity in the industry. This indicates that the effect of government policy on industrial operations is confirmed (Figure 1), and governments worldwide are seeking effective green policies.

Supply Chain Behaviour

Organisations are becoming increasingly interested in green production as a result of the pressing environmental issues (Barari et al., 2012; Saberi et al., 2018). The concept of “green” has become ubiquitous among industries, and thus companies today are willing to integrate the concept of “green” into their supply chain managerial strategies. Additionally, sustainable development is often taken as a useful strategy in the competitive market. The greenness of a product is promoted in the supply chain to then encourage green activities such as recycling, remanufacturing, and reusing among businesses. By looking at the product manufacture in many industries, it can be found that the supplying process is incomparable to what it was before; for example, the combination of forward logistics and reverse logistics in the supply chain and the shifting of the focus of product design, have been introduced.

Specifically, the forward supply chain is the process of delivering the product to the market, and the reverse supply chain is the adding of environmentally friendly elements into the supplying process (Carter & Ellram, 1998). Becoming green can not only help to gain market share but also contribute to the sustainability of the business. The above evidence suggests that supply chain operation is changing as a result of sustainable development.

Due to the increase in environmental consciousness, the behaviour of the decision maker in the supply chain is changing; not only from the point of view of researchers in operations management but also for supply chain practitioners and governments (Sarkis, 2003). Environmental consciousness is influential for the behaviour of both consumers and companies (Swami & Shah, 2013) so that policymakers attempt to implement green policy to provide greener products to the market in order to control emissions from the use of the products. In the past decade, the sustainable development of the industry has created pressure on enterprises (Seuring & Muller, 2008) that has driven them to consider not only profit but also the influence of product design. The necessity of integrating the environmental and business factors into company managers' decision making has been indicated in the literature (Sarkis, 2003). As the supply chain pursues sustainability, and because the implementation of the green policy by the government can change green supply chain behaviour, the government's role in implementing green policy must be emphasised (Zhao et al., 2012; Sheu & Chen, 2012; Chung et al., 2013). Supply chain pricing strategy (Sheu & Chen, 2012) and supply chain technology strategy (Zhao et al., 2012) are two areas of such policy making. Although government incentive has been identified as a significant factor to change supply chain decision making (Chappin et al., 2009; Coria, 2009; Dowson et al., 2012; Fischer et al., 2003; Jaffe et al., 2005), the particular ways in which it influences supply chain behaviour is still unknown. To address this question, the present study researches into the influence of government green policy on the change of supply chain behaviour.

In addition, product design is also becoming “greener” in many different industries. Fujii and Managi (2013) have studied the relationship between emissions and economic growth in a number of countries between 1970 to 2005. They indicated several industries, such as paper, pulp, and printing industries, wood products industry, and construction industry, which stayed “Green” during economic growth (the term of “Green” is defined as environmentally friendly in this study: a product produces less emission from the usage or production). This phenomenon suggests that the green trend was pursued in those industries when they were planning their supply chain strategy. Srivastava (2007) advocated furthermore that companies have the responsibility to protect the environment, which should be reflected in their product development, process design, operations, logistics, marketing, regulatory compliance and waste management. Based on the induction of the green concept in the supply chain, supply chain behaviour has been changing simultaneously.

2.4 Sustainability in supply chain management

Sustainability is becoming such an important issue in supply chain management (Ahi & Searcy, 2013) that beside profit, sustainability development has been its focus in the past decade. It was defined that supply chain contains delivery of information, materials, and money among the parties in a chain, and it is dynamic (Jain et al. 2006, 2007). Due both to industrial environment changes and the gradual increase in people's green awareness, traditional supply chains cannot fill all operating needs anymore. The operating needs in industries indicate the importance of emission reduction and energy saving. Hence, there are two new different types of the supply chain that link sustainability and the traditional supply chain, that is, green supply chain and sustainable supply chain (Ashby et al., 2012). No significant difference between those two topics has been indicated by previous literature; Ashby et al. (2012) defined both green supply chain and sustainable supply chain as considering the *sustainability* issue in supply chain management.

To the components of the traditional supply chain, the "green" element is added to constitute the green supply chain operation process. A green supply chain includes green strategy, green design, green purchasing, manufacturing process, logistics, marketing, and recycling (Zhu & Zou, 2011). In his illustration of the operating phases of the green supply chain, Sarkis (2003) complemented this list by adding procurement, production, distribution, reverse logistics and packaging. A green supply chain is more focused on the impact of production activities on the environment in that it balances the environmental issues and economic development, which further enhances/supports sustainability. It is gaining significant attention from consumers, industries, and governments (Vachon & Klassen, 2008). Organisations are also interested in green products because of environmental issues (Barari et al., 2012). To conclude, because supply chain management is becoming nature-friendly in terms of the development of the sustainability, the present project is interested in investigating product design/production associated with green technology in the field of supply chain management.

Sustainability has become an important issue for businesses to plan strategies. The relationship between sustainability and the company's performance such as the financial/economic, environmental, social and operational aspects have received significant attention by previous studies (Quarshie, Salmi & Leuschner, 2016). Business sustainability suggests that the strategies of an enterprise should focus on economic, long-term development, environmental, resilience, social, stakeholder and volunteer issues (Ahi & Searcy, 2013). It was indicated that sustainability is a popular term among businesses such as the mobility industry (Ma et al., 2018). To achieve sustainable development, enterprises should not only focus on short-term profit but also the sustainability of their business (long-term perspective). In the industry, the development of sustainability connects to various phenomena, for instance, corporate social responsibility activities, green products, green supply chain (Darnall, Jolley & Handfield, 2008; Zhu, Sarkis & Lai, 2007), and green technology development. These are all driven by the development of sustainability and have effects on supply chain decisions. A more detailed literature review of green products and the green supply chain is presented in the later section.

The development of sustainability not only changes the behaviour of the business but also that of the government. As environmental awareness increases, the government employs green intervention to control emissions such as greenhouse gases (Cohen et al., 2015). Green policies such as incentives (Coria, 2009; Diamond, 2009; Neto et al., 2008; Webster & Mitra, 2008; Jin, 2011), regulations (Chen, 2001; Chen & Sheu, 2009), and taxation (Coria, 2009; Sheu & Chen, 2012) have been conducted in the supply chain. The literature states that the government's policy making is influenced by sustainability planning (Brugmann, 1996; Preuss, 2007). Drawing on the above literature, it can be observed that the government's green policy making is driven by the development of environmental sustainability, and it can influence a business's strategy.

2.5 Green Technology and Green Products

Green technology is defined as energy-efficient technology (Gallagher & Muehlegger, 2011) or clean technology (Hall & Helmers, 2013). Green technology adoption is positively related to emission reduction (Krass et al., 2013). In the car industry, hybrid cars and electric cars are products of applied green technology (green cars), and they produce fewer carbon emissions than non-green cars. Daziano and Bolduc (2013) indicate that the adoption of green technology in the car industry is technology innovation, and green technology adoption is positively affected by the gasoline price (Diamond, 2009). Green technology is an environmentally friendly technology applied in product design and manufacture. This research employs the definition of Krass et al. (2013) which sees green technology as the emission reduction technology and argues that higher green technology tends to result in lower emissions in the use of the product.

Businesses often adopt green technology when pursuing sustainability development. It is observed that nowadays companies are more and more willing to add green elements into their products to reduce emissions. A previous study by Min and Galle (1997) argued that one of the main sources of emissions is the supply chain. They also suggested that this issue could be solved by product material reduction and waste elimination. For example, companies can change the product manufacturing procedure in order to reduce emissions. Furthermore, Zhuo et al. (2011) note that green technology innovation is a way to improve both material utilisation and waste reduction. That is, having better green technology can help industries to decrease the emissions caused by production activities. Therefore, green technology improvement of the supply chain is seen as a way to effectively reduce the produced emissions in this issue. The level of green technology indicates product greenness. The higher level of greenness incurs less emission from the usage. It is expected that a higher level of green technology is associated with less energy consumption and will thus lead to the reduction of emissions. In this research, green technology improvement is defined as the increase of green technology level between the specific observed time points.

"Green product" means that the product is manufactured by either green material, through green technology, or green elements are included in the process of delivering it to market, and that it is more environmental oriented than non-green products. Green products can help with environmental protection by producing less emissions, pollutions and waste (Ottman et al., 2006). A green supply chain is key for an enterprise to promote green products, and a "green product" is defined as representing environmentally friendly or sustainable products (Cao et al., 2013). Green product innovation has been proven to be an effective and efficient approach in achieving environmental sustainability (Dangelico & Pujari, 2010). With the growth of the economy, more market consumers, supply chain parties and governments are interested in green product than before (Chen, 2001). To improve a company's performance, the development of green products has gained businesses' attention (Chen, Lai, & Wen, 2006). Over the past decade, green products have been developed by companies to raise environmental awareness (Barari et al., 2012). It is indicated that green innovation is an important and efficient way to reach both economic and environmental success (Lee & Kim, 2011). Notably, green product manufacturing is often regarded as an approach for a company to gain profit and achieve environmental protection. Corporate competitive advantage is positively affected by its green innovation performance (Chen et al., 2006; Dangelico & Pontrandolfo, 2010). To conclude, green products innovation/development is becoming important for companies (Dangelico & Pujari, 2010) and has been conducted widely by businesses as a competitive weapon.

Previous research has indicated three main research topics of the green product, including strategic decision making and problem solving in business and product development, product design, and green marketing (Baumann, 2002). In addition, literature such as Oliver and Lee (2010), Tsay (2009), and Pickett-Baker and Ozaki (2008) has also focused on green product consumption. Oliver and Lee (2010) discussed green product design in the car industry and they indicated that the social value associated with green products is related to the intention of purchase. That is, customers' consuming preferences depend on the social value of the green products. Another study investigated green product consumption with regard to a response to the resource crisis in Taiwan, and it was found that consumers would buy green products because they believe using them can help to improve the environmental impact (Tsay, 2009). However, in some circumstances, consumers can only recognize cleaning products but not green products (Pickett-Baker & Ozaki, 2008). Although the trade-off between a green product's high price and its green technology has been discussed (Olson, 2013), consumers still tend to purchase green products from greener companies (Pickett-Baker & Ozaki, 2008). This phenomenon is due to consumers' believing that the greener product can bring more benefit either financially or environmentally. For example, saving on fuel consumption by driving a greener car and producing less emissions from use. It is expected that the greener the product is, the more market sales will occur (Pickett-Baker & Ozaki, 2008). Thus, the degree of greenness is a key issue associated with green product demand in the market. In the supply chain, it is noteworthy that the supplier has the power to decide the green degree of raw materials (Cao et al., 2013), while the manufacturer has the power to lead the "green degree of the product" by changing its green technology level. Supply chain roles can determine their green technology levels and thus influence the market demand of green products (Pickett-Baker & Ozaki, 2008; Lee et al., 2013). The supplier and manufacturer are recognized as the two main and most influential roles among supply chain parties that impact on the greenness of a product (Lee & Kim, 2011).

2.6 Sustainable/Green Supply Chain Management

Sustainable/green supply chain is a type of managerial and operational tool which focuses on environmental protection and resource economizing (Samir, 2007). Green supply chain management is defined as the work that has been done in order to reduce the environmental impact caused by the supply chain activities (Swami & Shah, 2013). Previous studies regarding green supply chain management tended to focus on the issue of purchasing, operation, marketing, logistics, and reverse logistics (Sarkis, 1995). Recently, other topics have also attracted academic interest, such as green supply chain modelling (Cabral et al., 2012; Sarkis, 2003; Zhu et al., 2008; Chen & Sheu, 2009; Ghosh & Shah, 2012; Mirhedayatian et al., 2013; Zhu, 2013); reverse logistics in supply chain (Thierry et al., 1995; Jayaraman et al., 1999; Fleischman et al., 2000; Savaskan et al, 2004; Bia & Sarkis, 2013), and green supply chain operation strategy (Lam et al., 2013; Cao et al., 2013; Swami & Shah, 2013).

Green supply chain management is an operational activity of reducing environmental ruin, enhancing ecological efficiency, albeit keeping the same profit and market share (Buyukozkan & Cidci, 2012). It was stated that the elements of green supply chain management include product life cycle, life cycle of operation, measuring performance, and environmentally organisational policies (Sarkis, 2003). Sustainable supply chain management considers not only economic but also social and environmental performance (Carter & Rogers, 2008). Sustainable supply chain management is considered as an extension of Green supply chain management, and some research also confirmed the overlap in definitions between sustainable supply chain management and green supply chain management (Ahiv& Searcy, 2013). It was argued that green supply chain pays more attention to environmental issues, while sustainable supply chain management focuses more on economic and social impacts (triple bottom lines focus). In this thesis, both issues on green supply chain management and sustainable supply chain management are addressed by looking at the topics of carbon emissions (green technology adoption), supply chain profit, consumer benefit (price change).

Green supply chain activities such as used products collection and sorting, product reusing, recycling, and waste disposal (Rebitzer et al., 2004) are new concepts to the traditional supply chain. The operating phases of green supply chain contain procurement, production, distribution, reverse logistics and packaging (Sarkis, 2003). There are two main differences between green supply chain and the traditional supply chain. First, compared to the traditional supply chain, green supply chain adds reverse logistic which collects the used product and remanufacture rather than dispose of them as waste. Second, green supply chain has its own constructs including green strategy, green design, green purchasing, and recycling (Zhu & Zou, 2011). On one hand, green strategy drives a company to make business decisions towards a more environmentally friendly direction (Olson, 2008), while green design focus more on life cycle assessment and environmentally conscious design than non-green product design (Srivastava, 2007). On the other hand, green purchasing can help to reduce environmental impact from the consumption (Liu et al., 2012), and recycling has the same environmentally friendly effect that reduces the total consumption of materials. The concept of "green" in sustainable supply chain indicates an environmentally friendly design, which results in less carbon footprint. The green product is the output of a green supply chain and sustainable supply chain and it has less environmental impact than non-green products.

As the product of a green supply chain, green products have a different product life cycle in comparison to non-green products. There are two reasons for this. Firstly, green products frequently contain reverse logistics such as recycling, as well as recovering/reusing and remanufacturing, and the product life cycle is more complex than that of non-green products. However, it was indicated that remanufacturing activities will not be suggested when a company attempts to optimize both its financial and environmental costs (Bazan, Jaber, & El Saadany, 2015). Thus, it is still controversial to conclude whether remanufacturing can bring benefit to a company both financially and environmentally. Secondly, resource consumption, material preparation, production process, and the product end-of-life of green product are different from non-green products, and they cause different levels of environmental impacts (Rebitzer et al., 2004). This indicates a difference of carbon footprint between green and non-green products. Because of its greenness from either green material, green production process, or product green design, using green products can produce less carbon emissions than non-green products. Based on the two reasons above, green products generate less consumption compared to non-green products in two ways. First is through recycling and remanufacturing in the supply chain, and the second is via applying green design into the supply chain so that less emission will be produced during its use. This project focuses on investigating the second way because that is considered to be the more efficient approach to reduce the emissions.

Previous studies have investigated the strategy of sustainability for green products from the point of view of supply chain management (Cao et al., 2013; Lam et al., 2013). For example, the operational strategy of green product development has been discussed (Cao et al., 2013). Implications have been provided regarding the strategy of raw material procurement in the supply chain. In a mathematical modeling paper, Lam et al. (2013) have built a two-stage game theory model of green strategy that is related to resource utility and carbon footprint reduction. The study applied game theory to describe the interactions in supply chain; the model also considers the efficiency of resource using and the reduction of emissions at the same time. The coordination between manufacturer and retailer in a green supply chain has been addressed by Swami and Shah (2013). They investigated the contribution of the manufacturer's and retailer's decision making to a sustainable supply chain. It is believed that supply chain behaviour is different in a green supply chain to a traditional supply chain. Supply chain operations connect to greenness/sustainability closely in a green supply chain, and these behaviour changes bring benefit to their performance. In a green supply chain, research has discussed the impact on environmental performance, economic performance and operational performance of supply chain behaviour change (Fang & Zhang, 2018). The argument coincides with the concept of triple bottom lines (3BL) in sustainability development which includes the environmental, financial and social perspectives (Norman & MacDonald, 2004). From the above review of the literature, it can be concluded that the idea of "green" development in the supply chain impacts on supply chain behaviour, and this phenomenon influences the supply chain's environmental, economic and operational performances.

2.7 Government Intervention in sustainable supply chain

The role of governments is important and influential for sustainability development in supply chain management (Zhao et al., 2012; Sheu & Chen, 2012; Chung et al., 2013). With regard to this, the literature has revealed that the implementation of green supply chains could be achieved through government intervention (Georgiadis, 2004; Sheu et al., 2005). Government intervention can influence the strategies of the parties (i.e. supplier and manufacturer) in the green supply chain (Zhao et al., 2012). To promote the idea of *green*, such as green activities and green products, the government should establish green policies such as subsidies, taxes, or incentives toward green products. It is known that the government also has an influential role in green supply chain development in terms of the financial capability to support industries. Furthermore, governments are under pressure from international environmental regulations (Hitchcock, 2012), and it is a governmental responsibility to adopt a green policy. Sustainability has also become important for governments because of climate change assessments (Barari et al., 2012), such as the Kyoto Protocol and the EUETS (European Union Emission Trading Scheme, EUETS) in 2005 which is currently the widest applied globally. EUETS is an emission regulation for 31 countries in the world, meaning that governments are facing regulatory pressure to develop sustainability (Hitchcock, 2012). In the UK, the Climate Change Act (2008) indicates that the UK government will provide a five-yearly green budget to support its target of carbon emission reduction by 2050. As pressure from national or global regulation increases, governments are more and more willing to support and even drive sustainable development in the present decade. Due to the above drivers and motivations, more and more countries' governments are willing to participate in green development activities. In summary, the literature above shows the governments' motivation for investigating the green supply chain. Also, as known, a government plays a leading role in sustainable development. The green supply chain's parties' willingness to increase and improve green production technology is influenced by the government's carbon emissions policy (Zhao et al., 2012). Namely, a government's policy can be adopted to encourage green technology implementation. In this context, this study aims to illustrate the appropriate incentive strategy for governments and the optimal decision making for supply chains when receiving government incentives.

The topic of government incentive in green supply chain management has been well researched recently (Georgiadis, 2004; Chen & Sheu, 2009; Hafezalkotob, 2015; Jin et al., 2011; Neto et al., 2008; Sheu & Chen, 2012; Sheu et al., 2005; Webster & Mitra, 2008; Zhuo & Wei, 2017). Government intervention can be classified into incentive and disincentive. Incentive reveals a positive technique to promote sustainability and environmentally friendliness such as subsidies and financial incentives (Hafezalkotob, 2015; Neto et al., 2008; Webster & Mitra, 2008; Jin, 2011; Sheu & Chen, 2012; Zhuo & Wei, 2017). Disincentive, however, indicates a negative way to control emissions or resource consumption. For instance, there are the environmental regulations/policies (Chen, 2001; Chen & Sheu, 2009), waste penalty and punishment (Zhao et al., 2012), and taxation (Sheu & Chen, 2012). The review of both incentive and disincentive of government intervention in sustainable supply chain is included below.

Firstly, the literature indicated that government policy can lead the operating strategy of the supply chain (Zhao et al., 2012; Sheu & Chen, 2012) and that government provided support can help to promote green products (Webster & Mitra, 2008; Jin, 2011) and social welfare (Jin, 2011; Sheu, 2011). Government also has a power to integrate green supply chains (Georgiadis, 2004; Sheu et al., 2005). The influence of government's green intervention on supply chain management has been studied. Neto et al. (2008) have reviewed the influence of subsidies on the environmental impact and supply chain costs from the perspective of logistic network. Chen (2001) proposed a quality-based model concerning the development of new products with conflicting traditional and environmental attributes. In this model, he analysed the effect of interactions between the supply chain and the government's environmental policy on green product development. The result has shown that green product development and strict environmental regulations are not necessarily good for the environment. Thus, it is notable that not all of the government interventions influence positively environmental protection and the development of sustainability. Because the disincentives of green policies such as regulations and penalties, are applied consistently to all levels of green products and not differentiated by their greenness level. In the background case of Taiwan, the disincentives such as supply chain emission regulation can only control the emissions produced during the production process and not affect the products' greenness. In this case, disincentives are not greenness-dependent, and thus cannot directly drive the supply chain to manufacture greener products to avoid disincentives. Consequently, in this study, I only consider incentives and exclude the disincentives. In other countries, disincentives may have effect on product greenness, and thus the consideration of only incentives is seen as a limitation to the research in section 7.4.3

In a previous study, a two-period game theory model was built based on the notion of interaction between manufacturers and re-manufacturers (Webster & Mitra, 2008). They examined the effect of government subsidies as a means to promote the development of remanufactured products (considered as green product). The results suggested that governments should subsidize both producers and consumers rather than incentivize a single party. Another game theory model was established to find the optimal environmental-regulation pricing policy in green supply chain by Chen and Sheu (2009). They suggested that the government's regulation can promote the extended product responsibility for the companies. As the government makes the regulation stricter, the manufacturer will increase their product recyclability (green technology). Thus, this study aims to investigate the ability of the government's incentive policy to raise the green technology level of the green supply chain. The development of the green product, which addresses environmental issues through product design and innovation, is receiving attentions from practitioners and governments globally. Thus, the present project focuses on green product innovation to explore the influence of government incentive on supply chain behaviour.

From the government's perspective, a game theory model has been built in a previous study to investigate the government's optimal subsidy policy (Jin et al., 2011). Governments' goal was maximising social welfare and enhancing the demand of green products. Their results indicated that as the government subsidizes green supply chains, social welfare will improve and green product demand will rise. It was also noted by Jin et al. (2011) that green product prices will decrease in order to increase product demand for the green market. However, the market demand of the model has not considered the green level of the product, so they observed only the influence of subsidies on demand which is reflected by the change of price but not of green technology. It was proven that green technology has an impact on green product market demand (Pickett-Baker & Ozaki, 2008; Lee et al., 2013). Thus, the present study considers the government provided incentives to the supply chain parties, and investigates the affected change in supply chain behaviour (both pricing and green technology strategies).

The influence of government financial policy on the green supply chain has been discussed by Sheu and Chen (2012). They built a three-stage game model to illustrate how government intervention will promote a green product. Their results have indicated that governments provide taxation and subsidization to green supply chains as a way to promote green products. They concluded that through the government intervention, both social welfare and supply chain profit can be improved. With regard to the disincentive policy, it is indicated that government's punishment and penalty affect the manufacture's decisions, and disincentives can reduce the emissions by improving the manufacturer's production method (Zhao et al., 2012). This means that when the government increases the emission penalty, manufacturers will attempt to expand in green areas in order to avoid the punishment. Thus, it is assumed that the government green policy can drive the manufacturer to increase/improve their green technology level. In this study, it is considered that the government provides incentives to supply chain parties to encourage them to increase green investment and be increasingly environmentally friendly. This project considers the notion that governments should offer incentives both to the supplier and the manufacturer which are the two main supply chain parties who determine product greenness (Lee & Kim, 2011). This could reduce the likelihood of one company receiving the entire incentive fund as well as increase the green level of the product.

Although it is confirmed that government green intervention such as incentives can influence the supply chain operations (Chen & Sheu, 2009; Jin et al., 2011; Neto et al., 2008; Sheu & Chen, 2012; Webster & Mitra, 2008; Zhao et al., 2012), little is known about the influences of government intervention on environmental impact, supply chain's decision making and market demand (based on a triple bottom lines concepts). For this reason, the current research project aims to analyse the effect of government intervention on environment, economy, and society dimensions.

2.8 Automotive sector and its green practice

The automobile industry is widely regarded as a main source for GHG emission due to the large fuel consumption of its products (US EPA, 2016), and because car manufacturers increase the production efficiency towards mass production (Nieuwenhuis & Wells, 2007). Thus, in many countries, the automobile industry is targeted as a key point to reduce GHG emission (Van Soest, 2005; Barari et al., 2012). Among different kinds of green products in the market, the green car is targeted as one of the most important green products to develop, when society and the government seek environmental suitability. Within the automobile industry, the "adoption of green technology" is believed to be an effective way to reduce GHG emission caused by transportation (Mak et al., 2013; Gnann et al., 2015). McKinsey's global survey of 2007 showed that 38% of consumers believed that driving fuel-efficient cars was the most effective way to reduce the global warming (Bonini & Oppenheim, 2008). In the green car market, one of the most popular car models, the TOYOTA Prius, has sold 4.2 million cars by February 2018. Another example of green car model, Tesla, which not only have achieved significant market share in America but also has been successfully introduced into the Chinese market (Wells & Nieuwenhuis, 2012). Notably, the cumulated sale of all TOYOTA electric car models was 11.47 million up to 2017. This green car sales resulted in a 90 million ton of CO_2 reduction compared to the sales of non-green cars (TOYOTA MOTOR CORPORATION, 2018). This indicates that the development of green cars can significantly reduce carbon emissions, and this argument has also been confirmed by previous research (Lee et al., 2013). Other than TOYOTA, car brands such as Ford, Mercedes and BMW have also participated in green car technogy innovation (Wells & Nieuwenhuis, 2012). It can thus suggest that the recent green technology innovation in automotive sector has received significant attention by both supply chain parties and governments, due to that the development of green technology is proven to be an efficient way to reduce emissions.

Until 2014, carbon dioxide emission by transportation only accounted for up to 26% of the overall greenhouse gas (GHG hereafter) emission. However, human transportation activity has become the second largest impact on the environment after electricity (US EPA, 2014). In response to this, a variety of international environment agreements, such as the Kyoto Protocol and the EUETS (European Union Emission Trading Scheme, EUETS), emerged over the past few years, and governments across the world have been appealed to join them. In addition, due to the rise in consumers' environmental awareness, governments are also urged to address the issue of GHG emission. Governments' objective to maximise emission reduction (Cohen et al., 2015) has led to the introduction of various government green interventions, such as incentives, and this is recognized as an effective approach to control GHG emission by many scholars (Chappin et al., 2009; Coria, 2009; Dowson et al., 2012; Fischer et al., 2003; Fischer & Newell, 2008; Jaffe et al., 2005; Requate & Unold, 2003; Van Soest, 2005).

As this research focuses on government green intervention which tend to have influence on emissions reduction, the current green policies in different country are discussed as follows. In the U.S., the government is seen to implement green policies to stimulate the manufacturing of greener cars, and thus reduce fuel consumption (Krutilla & Graham, 2012). In the meanwhile, they also implement The Energy Policy Act of 2005, and provide subsidy to hybrid car buyers through the income tax system. In addition to the U.S., similar green policies and government incentives can also be found in many other countries and regions, such as U.K. (Plug-in vehicle grant), China (Technology innovation funding), France (Bonus-malus system), Germany (Electrical vehicle incentive program), Japan (Subsidies to purchasers of electrical vehicles), and Taiwan (Research funding for green technology development). It is evident that governments are stimulating consumers' demand for green vehicles and facilitating the development and adoption of green technology by manufacturers in an attempt to effectively reduce GHG emission.

Nieuwenhuis and Well (1997) contend that technology development in car industry is becoming more environmentally friendly in 21th century. Existing literature suggests two reasons that underpin automobile companies' investment in green technology. First, they invest substantially in the development and adoption of green technology in an attempt to improve fuel efficiency in their products and manufacturing process (Xu et al., 2013). It was indicated that a sustainable car product can lower total consumption in car industry (Nieuwenhuis, & Katsifou, 2015). Second, car companies seek to develop green products in order to cope with the ever-rising environmental awareness of consumers (Barari et al., 2012; Flammer, 2015). In addition to that, many governments adopted green policies to facilitate the corporate investment in green technology by sharing the financial burden and making it considerably more affordable than before. Government incentives are important for the development of green technology in automobile industry for two reasons. Firstly, in automobile industry, price reduction is the most influential factor for the diffusion of the green cars (Cecere, Corroche, & Guerzoni, 2018), and incentives can help to reduce the car price and promote sales. Secondly, green technology investment is long-term profit oriented, which contradict to the short-term objective of profitability in financial capital market (Cecere et al., 2014). The initiation of green technology innovation can be difficult, which indicates the importance of government's financial support. Incentives provided by the governments are proven to have a significant impact on the green technology adoption in hybrid vehicles (Diamond, 2009). The policies of green incentives in U.S. (Diamond, 2009), Netherland (Chappin et al., 2009) and Norway (Mersky et al., 2016) have also demonstrated a positive impact on green technology development in their automobile industries. Technology development is one of the production decisions made in supply chain management.

Since the decision on green technology development can be influenced by government incentives, this suggests that supply chain behaviour can also be influenced by government incentives and expectedly towards a more environmentally friendly direction.

It is found that governments tend over focus on emission reduction, so that supply chain parties in automobile industry require a better operational strategy to respond to government green interventions (Nieuwenhuis, Wells, & Vergragt, 2004). In order to increase the efficiency of government incentives in driving green technology development and adoption in the supply chain, it is important to understand both the ways the incentive should be given and the corresponding decision making in the supply chain. Existing literature tends to look at this issue from the perspective of the government, and thus lacks an understanding from the perspective of supply chain management. To address this gap, this study aims to examine the influence of government incentives on the development and adoption of green technology from the perspective of supply chain management, and illustrates the optimal decision making for supply chain management.

2.9 Conclusion

By reviewing the existing literature, this project attempts to fill the identified research gaps. First, the incentives, which depend on green technology, are considered when the government provides incentives to the supply chain. Although the influence of government green incentives on green technology innovation has been investigated in the literature (Diamond, 2009; Fischer & Newell, 2008; Phaneuf & Requate, 2002; Van Soest, 2005), no previous research has considered green technology dependent incentive which is currently applied in China and in the background case of this research, Taiwan. Because China has recently been recognized as the biggest source of GHG emission growth in the world (Boden et al., 2013), the impact of its government green incentives is significant. In order to drive green technology development by the government incentives, providing incentives based on supply chain's green technology performance is an efficient way. However, as green technology dependent incentives have not been discussed neither in policy management nor supply chain management research, this project aims to fill this gap in the literature.

Secondly, in incentive projects, both government policy-making and supply chain parties' decision-making are important to the adoption of green technology in the supply chain. A number of studies investigate incentives from the government's perspective (Chappin et al., 2009; Cohen et al., 2015; Diamond, 2009; Dowson et al., 2012; Gallagher & Muehlegger, 2011; Jena et al., 2018; Zhang & Wang, 2017). Others focus on supply chain management perspective (Fischer et al., 2003; Goulder & Mathai, 2000; Krass et al., 2013). None of the previous studies, however, have taken the government and supply chain's decision-making into account simultaneously, thus posing a gap in the literature, which the current project aims to address by integrating both government and supply chain's behaviour into the theoretical model.

Thirdly, this study aims to consider market uncertainty when investigating the influence of government incentives. Market uncertainties have been identified as key elements when modeling market demand (Bernstein & Federgruen, 2005; Burgers et al., 1993; Cardoso et al., 2013; Gupta & Maranas, 2003; Xiao & Yang, 2008). However, in the existing policy management and supply chain management studies, no study has considered market uncertainties such as price sensitivity and green preference in the market with regard to the influence of government green policy. The present project attempts to fill this gap by adding market uncertainty into the incentive model.

Chapter 3: Methodology

3.1 Research philosophy and methodology

Objectivism is an ontological position (Bryman & Bell, 2007), and objectivism advocates that the social phenomena and meanings of the social phenomena have an existence, and it is independent of the individual's perspective (Bryman, 2008). With regard to the questions of ontology within the social sciences, objectivism and constructionism are often considered as two main ways to discuss the nature of social entities (Bryman, 2008). Positivism was defined as an epistemological position, and Positivism proposes to use the natural science method to explore social reality and social phenomena (Bryman, 2008). Positivism advocates the existence of an objective reality that people can learn from (Jonassen, 1991). The research project supports the ideas of objectivism and explores the research topic under the guidance that social occurrences and their implications exist unaffected by individuals (Bryman, 2008). As the government provides incentives to supply chain parties, their behaviour is changed by the adoption of the incentive. It is believed that the influence of the government on supply chain behaviour is an objective fact that exists beyond any individuals, which a scientific examination can be used to explore. Accordingly, a mathematic model is built in the project to test the incentive influences by the government. Based on the positivist viewpoint, I can confirm the impact of incentives by examining the theoretically based model.

3.1.1 Mix-method adoption

Mixed method can address the research question more effectively than single research method (Malina, Nørreklit, & Selto, 2011). Mixed method is better than single method because it can ensure both validity and reliability of the research finding (Cadden, Marshall, & Cao, 2013). It was suggested that the choice of research method depends on the research questions instead of simply the epistemological or methodological considerations (Kelle, 2006). To address the research question of this research: "How do government incentives affect supply chain behaviours?", both modeling approach and the support of practical information, which can enable the model to optimally investigate the research question, are needed. Although quantitative modeling method is commonly applied in the field of operational research, qualitative approach is believed to reveal more information than quantitative approach when collecting practical data (Matthyssens, 2007). In the study of Hüttinger, Schiele, & Schröer (2014), qualitative method was used to collect the empirical evidence from automotive manufacturers at first. The findings from the qualitative analysis was then used to construct the framework of quantitative method. Their study has focus on factors which affect supplier's behaviour in terms of treating specific customers differently. In order to increase the reliability of the research, the authors used a qualitative approach to collect practical information to support and build the foundation for the quantitative method. In addition to Hüttinger, Schiele, & Schröer (2014), mixed method has been widely adopted in supply chain management studies (Cadden, Marshall, & Cao, 2013). Thus, this research employs mixed-method design to investigate the influence of government incentives on supply behaviour from a supply chain management perspective.

In order to answer the research question, this research project applies mix-method that utilizes both quantitative and qualitative methods. The mixed-method design in this research is based on three phases. It begins with a quantitative approach which is based on the extant literature. It is followed by a qualitative study which explores and gathers the necessary information from practice of car supply chain. Eventually, a quantitative modeling method is conducted to develop and build a comprehensive model that is based on the theoretical framework from phase 1 and conceptual framework from phase 2. Three phases are discussed in three sub studies respectively. Preliminary Study 1 and Main Study 3 used quantitative modeling method, whereas Study 2 adopted qualitative method to enhance and improve the model in Preliminary Study 1. Specifically, Preliminary Study 1 adopts a quantitative method on the basis of mathematical modeling. A game theory-based model is established in Preliminary Study 1 to develop an understanding of the influence of green incentives in supply chains. In Study 2, semi-structured interviews have been conducted in order to enable the development of the incentive model in Preliminary Study 1 into a simulation model. The qualitative data are adopted to verify and enhance the model. In Main Study 3, a simulation modeling approach is used to analyse the decision-making process of the incentive model. The structure of the mixed-method design is presented in the following figure.

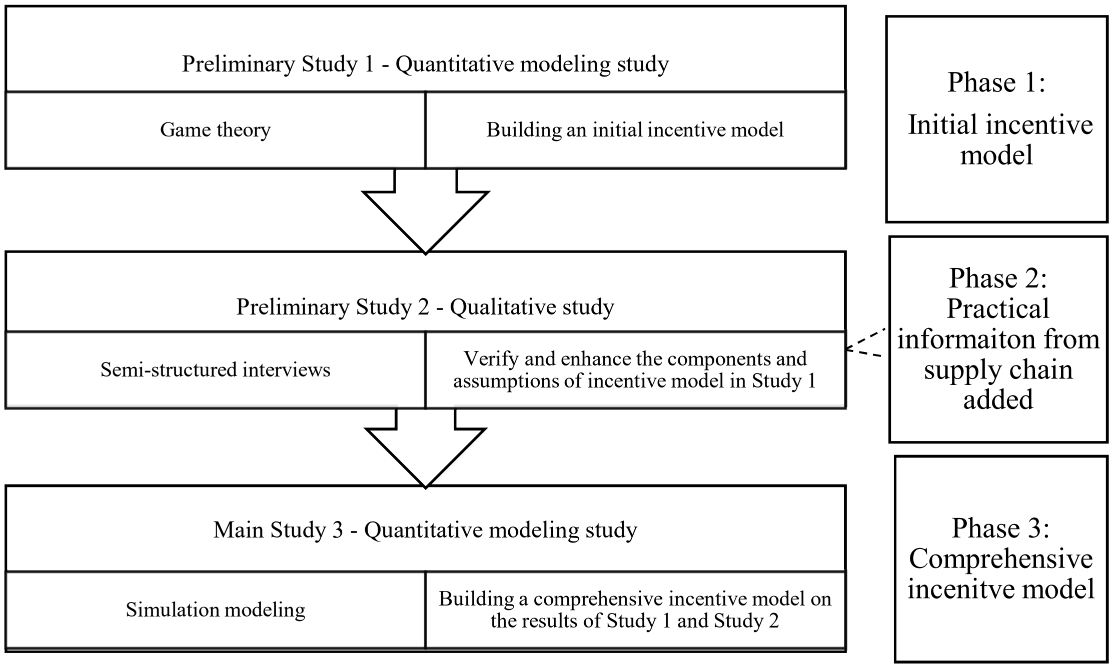


Figure 3 - The mixed-method design of the research

3.2 Selected methodologies applied in this research

3.2.1 Preliminary Study 1: Game theoretical modeling research

i. Understanding the influence of incentives on supply chain

Firstly, Preliminary Study 1 aims to investigate the influence of incentive on supply chain, market and environment, and find out how supply chain would respond to government provided incentives for green technology. This study verifies the effect of government incentive by observing pricing and technology strategies. I consider the government and the parties involved in green product manufacturing process (the supplier and the manufacturer). Game theory is applied to build the fundamental model of government incentive on green products. The justification of applying game theory model is discussed in the following section.

ii. Game theory

Game theory has been widely used in the studies of supply chain management and operation management (Esmaeili, Aryanezhad, & Zeephongsekul, 2009; Reyes, 2006; Huang & Li, 2001; Zhao et al., 2010), economics and management science. Methods applied in modeling the problems of green supply chain management vary across studies, but game theory (Jin et al., 2011; Zhao et al., 2012; Sheu & Chen, 2012; Ghosh & Shah, 2012; Zhang & Liu, 2013) and fuzzy theory (Tsai & Huang, 2009; Wang, et al., 2012; Wang, 2013) are predominantly used. Game theory is considered as a tool for analysing the interaction among decision makers that includes conflict and cooperation issue (Leng & Parlar, 2005) and can be used to analyse supply chain decisions (Lukas & Welling, 2014; Nagarajan & Sošić, 2008). That is, it can be applied in formulating/constructing the decision-making process of multiple parties. In this research, multiple decision makers are identified and modelled, thus game theory is an appropriate method to conduct the scenario.

Previous studies have adopted game theory to model the interactions in supply chain. Firstly, game theory is widely used in terms of the supply chain these days, paying more attention on the competition and cooperation issues (Leng & Parlar, 2005). For instance, Ghosh and Shah (2012) built a game model to check how different channel systems influence price, profit, and the green degree of each role in the green supply chain. Zhang and Liu (2013) employed four different models of green product demand considering game, that is, decision making with cooperation, one leader and one follower, Stachelberg game type I and II. Sheu (2011) also proposed a three-stage game model to formulate the competitive green supply chain based on governments' financial intervention. When more than three players are involved, game theory model becomes difficult to solve. Thus, game theory is normally used to describe the relationship between only two players. The preliminary Study 1 aims to formulate the interactions between supplier and manufacturer in government incentive project. Hence, according to the literature, game theory is an appropriate tool to analyse the green supply chains' decision-making process on the basis of the government's green intervention. Based on the foundation of the research background it is possible to suggest that information is shared among the parties, and this can be formulated as one of the scenarios in game theory mechanism. Accordingly, in Preliminary study 1, game theory is adopted to create the theoretical research framework of government incentive project.

As Preliminary Study 1 aims to establish a model including the government, the supplier and the manufacturer, whose decisions are influenced by each other's decisions, game theory appears to be an appropriate tool to be used in Preliminary Study 1. In order to focus on the unique interaction between supplier and manufacturer in the supply chain, two-stage game theory model, which is commonly used by supply chain management studies (Bhattacharya, 2016; Cai, Chiang, & Chen, 2011; Chen et al., 2018; El Ouardighi, 2014; Huang & Li, 2001; Zhang and Liu, 2013), is chosen in the research. First stage of the model focuses on the supplier's decision making, whereas the second stage of the model focuses on the manufacturer's decision making. To solve the game problem, it is assumed that supplier and manufacturer are under the scenario of perfect information game. Games of perfect information indicate that the players in the game are aware of each other's decision information when making decisions (Gale & Stewart, 1953). In each stage of the game model, single optimisation problem is used to formulate the player's objective function with constraints. The application of optimisation problem in game theory model were found in many studies of supply chain management (Ghosh & Shah, 2012; Gjerdrum, Shah, & Papageorgiou, 2002; Sheu, 2011; Zhang and Liu, 2013), thus this research also forms optimisation problems to describe supply chain behaviour based on the requirement of the game model.

Nash equilibrium is a common way to present the optimal solutions of the game model (Rosenthal, 1981). By following Rosenthal (1981) and Ben-Porath (1997), Nash equilibrium and backward induction were used to obtain the optimal solutions in this study. In this two-stage game model, it requires backward induction technique which solves the optimisation problem (Reny, 1993) from the later decision maker to the former decision maker. In Preliminary Study 1, supplier makes decision first and manufacturer responds to supplier's decision. Hence, in backward induction, manufacturer's optimal solutions are solved first and then these optimal solutions will be taken into supplier's objective function to gain supplier's optimal solutions. The components and assumptions of the game model will be discussed in detail in Chapter 4.

3.2.2 Preliminary Study 2: Qualitative empirical research

i. **Practical information collection for incentive model verification and establishment**

The present project aims to create a both theoretical and practical based product incentive model. To develop an incentive model which considers the operating background of the supply chain should not only be based on theory but also rooted in industries' practical knowledge. It is indicated by Wright et al. (1996) that pure model based statistical approaches lack proper historical, economic, and technical information, and suggested that including human judgment is a way to fill the shortage (Wright et al., 1996). As a result, Study 2 adds the experts' perspectives into the model design.

Supply chain management is for managers in the industry, it is necessary to collect information from practice in order to fit the industrial operations. Previous research often adopted qualitative methods to gather the industrial information to construct the frame of supply chain. For example, case study (Towers & Burnes, 2008; Youn et al., 2012), focus group (Lu et al., 2013), and interview (Fawcett et al., 2007; Wild & Zhou, 2011; Perry & Towers, 2013). Previous studies have used interview data to build the framework of the supply chain, for instance, Wild and Zhou (2011) developed a conceptual framework of the supply chain operations among the non-government organisations, they used in-depth interviews to explore empirical knowledge. In a similar study, Fawcett et al. (2007) employed semi-structured interviews and surveys to collect industry data in order to know information sharing and supply chain performance. In a recent study, a conceptual supply chain framework was built by Perry and Towers (2013) in relation to CSR implementation in the fashion manufacturing industry. They collected the interview data from the managerial and operational level staff from companies as well as from non-participant observation of the industrial environment. Interviewing industrial insiders is an appropriate method to structure the supply chain operations framework. The opening question of a semi-structured interview can help to capture richer and wider information without missing focus (Gill, et al., 2008). Hence, in the second study of the research project, semi-structured interview has been chosen to explore the supply chain framework in the car industry.

ii. Semi-structured interview

To gather rich information from practical perspectives about the car industry supply chains, the government incentives on green products, and the interactions among supply chain parties in the incentive project, an interview is conducted following the game theory model in Preliminary Study 2. For the research topic of this research project, which has been investigated by the literature, different professionals, and educational and personal histories of the participants, the use of a standard interview schedule/procedure has been suggested (Barriball & While, 1994). Semi-structured interviews make it possible to explore the perspectives, viewpoints, experiences of the participants (Gill, et al., 2008), and the interview will start with a list of prepared questions to ensure the collected data is focused correctly. In the semi-structured interview data analysis, the study will identify the majority of themes and follow the main themes to develop the incentive model framework. Collected data will be analysed with software to ensure the quality of the procedure. Thus, semi-structured interview is adopted in this research to capture essential information. Following Gill, et al (2008), a list of prepared questions will be asked. Then the interviewee will be given deeper/further enquires upon the initial response. This research also follows the guidance of Brenner, Brown, and Canter (1985) to reduce interviewer bias. During the process of interviewing, each participant will mainly focus on one specific topic that he/she is familiar with. For example, the manager of the car company will be asked only car supply chain related questions instead of those regarding green products or government incentive. Thus, the depth of the interview is ensured by setting the interview questions in advance. The participants will be drawn from the managerial level of a company, who are believed to possess the decision-making power. Drawing on the literature, 10 to 12 interviews are planned (Gaskell, 2000). After the data collection, a qualitative analysis software, Nvivo, will be conducted to analyse the semi-structured interview data to gain the main/sub themes. Details of the semi-structured interview will be discussed in Chapter 5.

3.2.3 Main Study 3: Simulation modeling research

i. Simulation method

Simulation approaches have been widely applied since early 1990s, focused mainly on the decision-making context in supply chain operations (Jahangirian et al., 2010). These approaches provide a useful tool to formulate/construct multiple parties with autonomy, and consider the interaction among the players/parties (Macal & North, 2006). In the field of economics, simulation modeling is well known as a tool to enlarge problems that are to be explored (Arthur et al., 1997). In the relevant studies, Amini et al. (2012) have employed the simulation method to analyse the profits under different production-sales policies, by simulating the interaction process of the supply chain and the market to obtain the best policy. In a review paper, Santa-Eulalia et al. (2012) indicated that modeling and simulation are frequently employed to understand and explore complex supply chain systems, and identify, for instance, the problems of planning, scheduling, coordination, and dynamic. In Main Study 3, multiple parties will be associated with the incentive providing process. All of these relevant parties will be involved in the decision-making system, and they will interact with others. This is why simulation has been considered to be an appropriate tool for capturing the decision making among the parties involved. The game theory model in Preliminary Study 1 only considers the government, the supplier and the manufacturer. However, as the number of parties included in the research increases in Main Study 3, the simulation model becomes more appropriate than game theory for the study, because the simulation approach is not constrained by the number of parties in the model, nor the complexity of the decision-making process. Hence, in order to formulate the decision-making process in the green products incentive model among multiple parties, Main Study 3 adopts the simulation modelling approach.

In addition, simulation can be used to model complex environments such as the supply chain (Slats et al., 1995), and it is suitable to solve mathematical models that include complicated decision making (Macal & North, 2006). This study attempts to investigate supply chain’s behaviour under the given government’s green incentives.

Simulation is an appropriate method to analyse decision making in the supply chain (Tako & Robinson, 2012). Compared to the traditional simulation, which takes a "what if" approach, this study adopts a combined approach, which integrates simulation and optimisation, and thus increases the efficiency of analysing continuous decision variables such as incentives and pricing decisions in supply chain models (Wan et al., 2005). Having combined game theory with optimisation and simulation method, a stochastic simulation model will be developed to investigate the supply chain pricing and technology strategy. The dynamic factor in the model is the demand uncertainty, which is illustrated by the green technology sensitivity factor and price sensitivity factor. Details of the simulation model are presented in Chapter 6.

ii. Simulating the decision-making process of the incentive model

The mathematical model built in Preliminary Study 1 has been verified and adjusted in Preliminary Study 2, which formulates the real-life case more precisely. Because of the practical information added into the incentive model in Preliminary Study 2, the complexity of the model increases. Specifically, complexity of the model increases due to more participated parties is considered and the mechanism of decision-making process in the incentive model is more complicated than only one supplier and one manufacturer in Study 1. Main Study 3 thus relaxes the constrains and assumptions from game theory model to formulate the details of the multi-period incentive project which fits the reality closely. Optimisation-simulation modeling is used to formulate the interactions and behaviour between the government, supply chain parties and market consumers. The influence of other's responses on their own decision making can be reflected in the simulation process. A comprehensive simulation-based incentive model is demonstrated in Main Study 3 in order to understand the influence of government incentives on supply chain behaviour, especially on the green technology adoption. Sensitivity analysis is then conducted to confirm the relationships between parameters and decision variables. In addition, different government incentive strategies are compared via numerical analysis to provide the implications of government green policy management.

Chapter 4: Preliminary Study 1: Game theoretical modelling research

4.1 Introduction

To respond to the research question "*How do government incentives affect supply chain behaviours*?", Preliminary Study 1 examines the influence of government incentive based on the concept of triple bottom lines. In order to understand whether the government incentive has a positive influence on the 3P (people, planet and profit), these concepts are tested differently. Influences on product price and green product demand are considered for the "people" concept; influence on the green technology of the supply chain leads to the "planet" concept; and influence on supply chain profits are linked to the "profit" concept.

To investigate the influence of government incentive on the supply chain on the basis of considering the relevant parties' interactions, an analytical approach is adopted in this study, which is also used in the literature of green supply chain management (Jin et al., 2011; Zhao et al., 2012; Sheu & Chen, 2012; Ghosh & Shah, 2012; Zhang & Liu, 2013). Specifically, the mathematical game model is used to formulate the decision-making process of the government, supplier and manufacturer. The Preliminary Study 1 aims to examine the influence of government incentive on supply chain decisions. Existing literature suggests that game theory model is a suitable approach to analyse supply chain decision making (Lukas & Welling, 2014; Nagarajan & Sošić, 2008). When there are conflicts and cooperation between involved parties, game theory model is a useful tool to illustrate the interactions among decision makers (Leng & Parlar, 2005). In Preliminary Study 1, it is considered that the government provides incentives to supply chain including the supplier and the manufacturer, and cooperation is in existence between them. Hence, game theory model is suitable to be used to capture this scenario. Game theory has also been adopted to build the government incentive model regarding the interaction among parties in the supply chain (Mitra, 2008; Jin wt al., 2011; Chen & Sheu, 2009; Sheu & Chen, 2012). Thus, the study employs game theory as a foundation to establish the green supply chain incentive operating framework, and then to analyse the influence of incentives from the 3P (people, planet and profit) perspective.

Firstly, supply chain activities consist of material and information delivery among each party (Jain et al. 2006). During these transfer processes, decision making is an issue in supply chain management as it determines the cost, profit and the competitiveness of the industry. To maximise payoffs, the decision maker considers all the conditions and available options. There are different dimensions of decision making discussed in the literature, such as operation strategy (Lam et al., 2013; Cao et al., 2013; Swami & Shah, 2013) and green supply chain model (Cabral et al., 2012; Sarkis, 2003; Zhu et al., 2008; Chen & Sheu, 2009; Ghosh & Shah, 2012; Mirhedayatian et al., 2013; Zhu, 2013). Similarly, to most of the literature, the present study also focuses on the green strategy (green technology level) and the pricing problem.

It is notable that although there are several parties in the sustainable supply chain, the supplier and the manufacturer are identified to be the most influential supply chain parties to the greenness of a product (Lee & Kim, 2011). Drawing on previous work on the green issues, the present research project aims to investigate green technology in supply chain. When the government provides no disincentives, only the supplier and the manufacturer are involved in technological decisions, thus this study takes both the supplier's and the manufacturer's behaviour into consideration. Webster & Mitra (2008); Chen & Sheu (2009); Zhao (2012) have indicated the importance and their influences on the supply chain decisions. In the supply chain operations, market demand is also involved in the game model, together with pricing and technology decisions that are considered in Preliminary Study 1. It is assumed in this study that the supplier and the manufacturer will independently determine the technology investments and pricing levels based on market demand information and government incentives. Incentive decisions are made by the government to support green technology adoption in the supply chain.

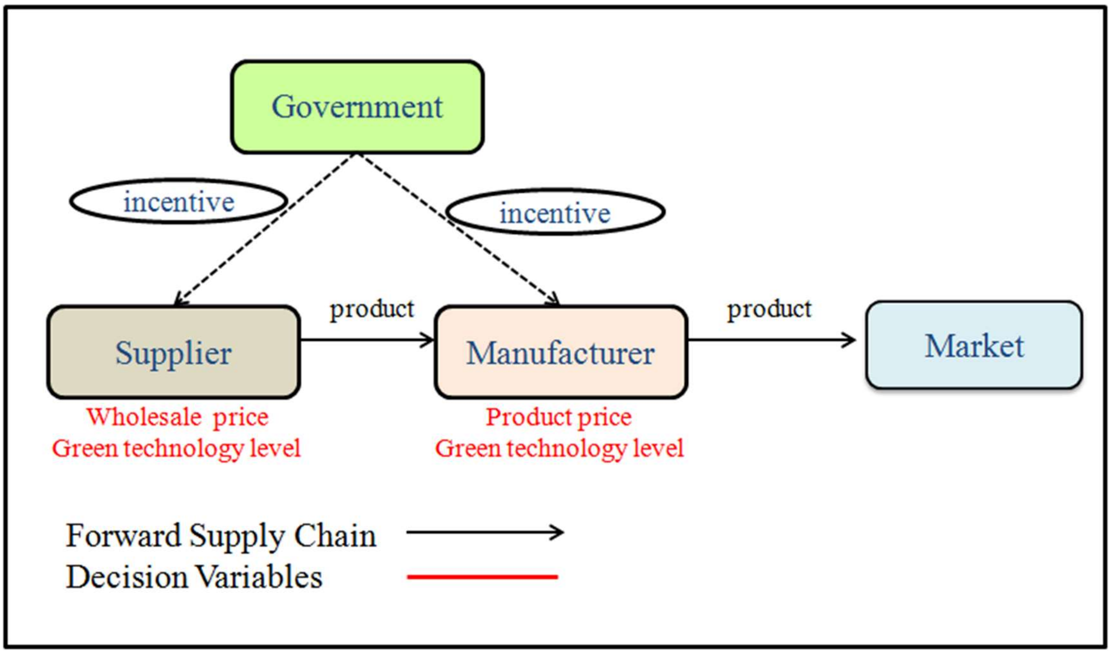


Figure 4 - Framework of the incentive model

Figure 4 is the operations of the model in the study. The solid black line represents forward logistics and the red wording represents the decision variables of each party. First, the government leads the operating process in this study. It is assumed that there is a supply chain with one supplier and one manufacturer. In the supplying procedure, the supplier spends a certain amount of money to buy raw material and processes them into a productive material. Those materials then will be sold to a manufacturer at a wholesale price determined by supplier. Next, the manufacturer uses the purchased materials to manufacture the products and deliver them to customers in the market. The market demand function is affected by both the supplier's and manufacturer's green technology level, and both their objective functions include demand function. Thus, demand function is the component that links supplier and manufacturer's profit.

Expected themes of Preliminary Study 1

Preliminary Study 1 aims to test the incentive influence by examining the responses of the people, planet and profit. The concept of the 3P is presented in expected theme 1 and 2 in the present study. Firstly, it is assumed that the goal of the government is to pursue the 3P in terms of being environmentally friendly due to the pressure of international regulations. In the literature, Chen and Sheu (2009) and Zhao et al. (2012) have indicated that government intervention can positively promote the green product market demand. Furthermore, Sheu and Chen (2012) confirmed that the government's financial support can successfully promote green products to the market, increase the green supply chain profit and improve green technology (Cao & Yao, 2013; Zhao et al., 2012). According to the literature above, I expect the relationships between government financial incentives per unit and the 3P as follows:

Expected theme 1: The amount of financial incentive per unit from the government has a positive influence on the people (i.e. price, market demand).

Expected theme 2: The amount of financial incentive per unit from the government has a positive influence on the planet (i.e. green technology level).

Expected theme 3: The amount of financial incentive per unit from the government has a positive influence on supply chain profits (i.e. profits of the supplier and the manufacturer).

In supply chain operations, it often happens that the supplier and the manufacturer are not in a cooperative relationship and are considered as two independent parties. Cao and Yao (2013) indicated that green incentives on suppliers can expand their R&D technology. On the other hand, Graczyk (2011) discussed the subsidy on the manufacturer and Zhao et al. (2012) confirmed that the government policy impacts on improving the manufacturer's green production technology. According both to the supply chain practice and the literature, the supplier and the manufacturer are independently influenced by the government's strategies. Similarly, these may cause the green incentive to have various impacts on the supplier and the manufacturer. Hence, there is an expectation as follows:

Expected theme 4: The influence of the financial incentives on the manufacturer and the supplier is different, that is, the response of the supply chain varies among parties

Due to the supplier aims to maximise their profit, adjusting the pricing decision is a way to respond to the market environment. Sheu and Chen (2012) suggested that the green supply chain will change the pricing strategy (wholesale price and product sale price) to maximise their profits when the government provides financial support. Hence, in the game model, the supplier and the manufacturer consider the market conditions when setting the wholesale and the product price, and decide their green technology levels. The price, therefore, may be affected by the incentive.

Expected theme 5: The financial incentives from the government will change the pricing strategy of the supply chain and decrease the market price of the product.

4.2 Method

4.2.1 Assumptions

(1). It is assumed that there is a perfect information game and there exists a sub-game perfect equilibrium in the incentive model.

(2). Market structure is a monopoly, the competitor's price is considered as given and the influence of the monopolist's price on others' pricing strategy is ignored (Krugman & Obstfeld, 2008). There is only one supplier and one manufacturer in the same supply chain. Because these two parties are usually included as influential roles in the supply chain in similar studies (Webster & Mitra, 2008; Zhao, 2012; Jin & Mei, 2012), Preliminary Study 1 also takes them into consideration and Preliminary Study 2 and Main Study 3 will reflect more supply chain parties in the model.

(3). The green product demand is extended by the linear demand curve ($demand = a - bp$, $demand = market\ size - effect\ factor \times price$). A linear market demand has been applied by Constantinides et al. (1981) in a maximum-profit objective function, this study formulates the market demand function on the basis of Constantinides et al. (1981). Furthermore, the model considers that the "green technology" in the supply chain will affect the demand. The higher the green technology levels of the supplier and manufacturer, the higher the demand. The demand function will be: $\left(a - bp^{*} + c\left(\alpha T_s + \beta T_m^{*}\right)\right)$ while the T_s and T_m represents the green technology levels of the supplier and the manufacturer. The rate of green technology indicates the improvement of emissions reduction, that is, in comparison to the previous level of emission produced by the product use, the percentage of emission reduction reflects the improvement of green technology level. α indicates the factor determining supplier's green technological influence on overall greenness, and β is the factor determining manufacturer's green technological influence on overall greenness. Thus, in the demand function, it is assumed $\alpha + \beta = 1$.

4.2.2 Framework of the model

Regarding the game model of this study, it was explained in the Introduction that the government aims to promote green products in the market. At the same time, however, the objective of the manufacturer and the supplier is to maximise their profits. The decision variable for the government is the incentive paid to each party, and the manufacturer and supplier's decisions are their prices and green technology levels. Due to pricing strategy being the most decision-making focus, the current study considers wholesale prices and product prices as dependent upon the supplier and the manufacturer's decisions. Apart from pricing, the green technology level is also considered as a decision variable for the supply chain.

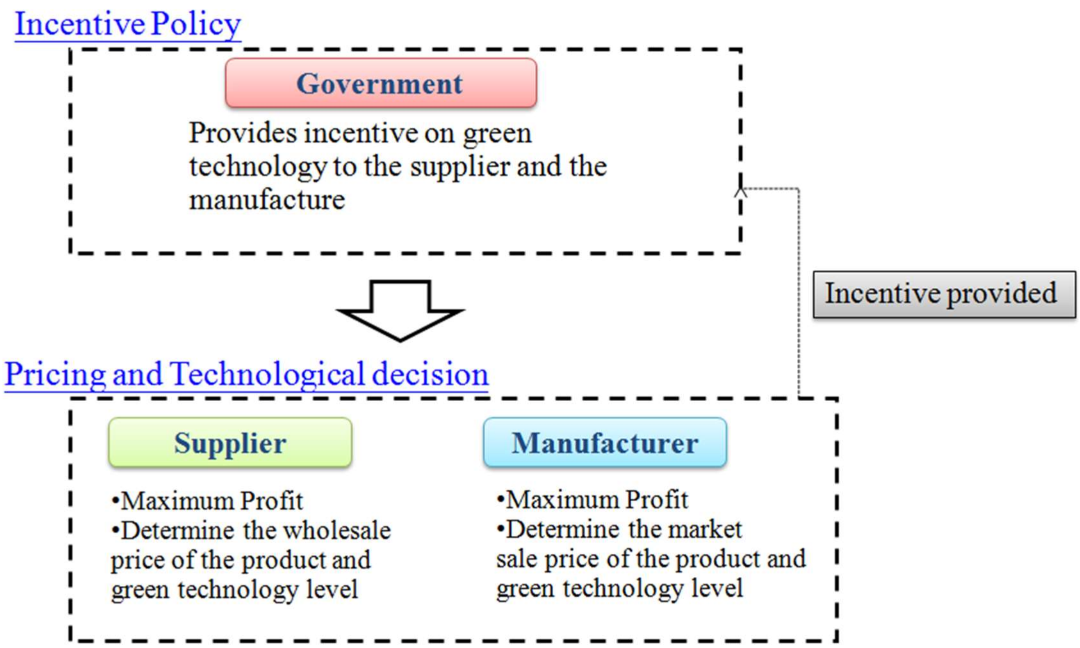


Figure 5 - Decision process of the Game model

This study builds a game model with regard to the interactions between the government, the manufacturer and the supplier. It is assumed that these entities make decisions based on precise and accurate information. First, the government announces its incentive scheme to both the manufacturer and the supplier. Next, the supplier determines the optimal decisions on the basis of maximising profit, and the decisions include wholesale price and green technology level. The information of the decisions from the supplier will be delivered to the manufacturer, to whom the incentive rate, wholesale price, and the supplier's green technology are given. Then, the manufacturer has to determine the product market price and the manufacturing green technology level based on knowing the incentive from the government and the supplier's decisions. The structure of the decision process of the incentive model is shown in Figure 5.

This study will use backward induction to solve the sub-game perfect Nash equilibrium for this mathematics game model. First, it will solve the decision of optimal price and green technology level maximising the profit of the supplier. Next, I substitute the optimal pricing and technology decision into the manufacturer's profit function to determine the decisions. The detailed process of obtaining optimal solutions is presented in section 4.2.4.

4.2.3 Formulation of the game model

I Green technology level

The present study defines green level by evaluating the levels of emission prevention and treatment in technologies. High green technology can reduce the emissions of the product use and the environmental impact. Considering different green technologies have different grades,and involving more green elements (with lower emission) indicates a higher score. According to the regulation of the EIPPCB (European Integrated Pollution Prevention and Control Bureau), the definition of green technology contains certain techniques that can reduce/minimize environmental pollutions and emissions. Thus, this project considers that green technology is positively related to environmental friendliness, and technology level varies for each party. In this research project, the supplier and the manufacturer have their own technology decisions to make.

In this study, green technology level indicates the percentage of the green improvement compared to the default level: the higher the level, the more environmentally friendly the improvement. More environmentally friendliness means less emissions from the product use and less environmental impact from the product waste. When the T_s equals 0 it means the supplier has put no effort into improving green technology in the supplying process. Similarly, T_m equals 0 represents the manufacturer's lack of investing in green technology, and thus a lack of improvement in green manufacturing technology. In other words, the higher T_s and T_m will need more green investment from the supply chain (cost) but will be more environmentally friendly.

T_s : Level of green technology adoption by supplier

T_m : Level of green technology adoption by manufacturer

II Government incentive

To promote green environment friendliness, I propose that the government incentive rate should be based on the green technology improvement level. Namely, the amount of incentive depends on the supply chain's green technology level.

The incentives received by the supplier with a green technology level T_s :

$(T_s G_s)$

The incentives received by the manufacturer with a green technology level T_m:

$(T_m G_m)$

where the following definitions are applied:

G_s : The incentive rate given by the government to the supplier

G_m : The incentive rate given by the government to the manufacturer

III Market demand

In the green market, a company providing greener products can attract more consumers (Pickett-Baker & Ozaki, 2008). That is, the greater willingness to invest the manufacturer/supplier has the higher level the green technology will be. It is reasonable to assume that the "green degree" of the product may influence the demand in the market. Accordingly, I assume the greener the product is, the higher demand will occur in the green market; the demand function is presented below:

Green Product demand function: $a - bp^* + c\left(\alpha T_s + \beta T_m^*\right)$

where the following definitions are applied:

<u>Decision Variables</u>

p : The price of the product in the market

<u>Input parameters</u>

a : Market size

b : The factor of market price influence in the demand function

c : The factor of the overall green technology level influence in the demand function

α : Factor determining supplier's green technological influence on overall greenness

β : Factor determining manufacturer's green technological influence on overall greenness

However, green technology level is affected by the investment of technology development which shows there is a certain amount of cost in adopting/expanding the green technology. Namely, the green investment can raise the demand but also the technology developing cost for companies. Thus, the supply chain roles have to face a trade-off of the green technology investment and the increase of product demand. Enkvist et al. (2007) indicates that "low-cost" green technology improvement in terms of emissions reduction is widely applied by businesses. Lowering emission associated with consumption is relatively easy at first, but the cost rises when organisations aim to significantly change technology. Given this, it is assumed that the green technology cost for the supplier and the manufacturer is as follows:

Green technology improvement cost for the supplier: $T_s^2 C_{ts}$

Green technology improvement cost for the manufacturer: $T_m^2 C_{tm}$

where the following definitions are applied:

C_{ts} : The factor of improving green technology cost of the supplier

C_{tm} : The factor of improving green technology cost of the manufacturer

IV Marginal profit of product selling

For the supplier, revenue is from the wholesale activity of the product with the manufacturer, and it bears a cost too (the material cost and the cost of processing raw material to wholesale products). The government offers product incentives by product sales, this means that the government provides a certain rate T_sG_s to the supplier for every item that has been sold. Also, T_mG_m is the manufacturer's incentive for every item sold to the market. Wholesale price is w, and C_s represents the cost of the supplier. For the manufacturer, however, there is a cost "w" of buying products from the supplier and they can be sold to the market for price "p".

Thus, the marginal profit of the supplier and the manufacturer will be:

Marginal profit of the supplier: ($w - C_s + T_sG_s$)

Marginal profit of the manufacturer: ($p - w + T_mG_m$)

where the following definitions are applied:

w: The per-unit wholesale price charged to the manufacturer

C_s: Unit cost of production for the supplier, the unit cost of production for the manufacturer has been normalized to zero without loss of generality.

V Profit function of the supply chain parties

According to the definitions presented above, it is assumed that the government provides incentives to the supplier. That means the decision variable for the government is the amount of incentives to the supplier and the manufacturer, leading to the profit function of the supplier and the manufacturer as follows:

<u>Supplier's objective profit function</u>

$$\pi_s(w, T_s) = (w - C_s + T_sG_s)\ (a - bp + c(\alpha T_s + \beta T_m)) - T_s^2 C_{ts}$$

Manufacturer's objective profit function

$$\pi_m\left(p,T_m\right)=\left(p-w+T_mG_m\right)\left(a-bp+c\left(\alpha T_s+\beta T_m\right)\right)-T_m^2C_{tm}$$

where the following definitions are applied:

π_s : Profit of supplier

π_m : Profit of manufacturer

The Government's objective

The detail of the government's objective function will be presented in the Main Study 3. With regard to social welfare, Preliminary Study 1 attempts to focus on the combination of three dimensions from the concept of the 3P drawing on Fisk (2010) which is people, planet and profit. Thus, this study takes environment emissions, supply chain profit and market consumption into consideration of the government's objectives.

In summary, this study builds an incentive game theory model that considers the interaction of governments, the supplier and manufacturer. The construction is mainly based on the consideration of the responses of the supplier and the manufacturer. The model is built to illustrate the influence of the incentives on the supply chain and the market. This study will also investigate the incentive allocation to the supply chain. The sensitivity analysis and incentive allocation analysis are presented in the result section of this chapter.

4.2.4 Optimal pricing and technology level decisions of supply chain

Maple 16 and MATLAB 2012 are used for the optimisation problem-solving process in the present study. In the two-stage game model, a backward induction is conducted to obtain the optimal solution. There are two stages of decision making in the green product incentive model: the manufacturer makes the decisions after the supplier. Thus, in the procedure of obtaining the optimal solution, I solve the problem from the manufacturer first and backwards to the supplier, as shown below in stage 1 and stage 2. The notation of "*" is used to represent the optimal solution for decision variables.

Stage 1. Optimal solutions of the manufacturer

The manufacturer has two decision variables, the product price p and the green technology level T_m, all other parameters are considered as known while the manufacturer makes the decision, and it is a maximisation problem of the manufacturer's profit:

$$Max \quad \pi_m\left(p,T_m\right)=\left(p-w+T_mG_m\right)\left(a-bp+c\left(\alpha T_s+\beta T_m\right)\right)-T_m^2C_{tm} \tag{1}$$

Subject to:

$\alpha+\beta=1$, and $a-bp+c(\alpha T_s+\beta T_m)\geq 0$

Theorem 1. There is a unique optimal strategy including product price and the green technology level of the manufacturer in this model. The optimal solution maximises globally the manufacturer's profit in the supply chain model. See the proof of negative definition in Hessian matrix in Appendix 1.

The problem-solving process of the unique optimal pricing and technology level decisions is summarised as follows:

Assume that the manufacturer makes the product price in the market p and green technology level as T_m. The manufacturer pays the wholesale price w and considers a green technology marginal cost C_{tm} to maximise its profit, which is equation (1). Equating first partial derivative of $\pi_m(p,T_m)$ with respect to p, T_m to zero, I obtain:

$$a-bp+c(\alpha T_s+\beta T_m)-b(p-w+T_mG_m)=0 \tag{2}$$

$$-2C_{tm}T_m+\left(a-bp+c(\alpha T_s+\beta T_m)\right)G_m+c\beta(p-w+T_mG_m)=0 \tag{3}$$

By collecting terms in equation (2), given T_s, T_m and w, the optimal price is obtained as:

$$p^*(w,T_m,T_s)=\frac{a+bw+c\alpha T_s+c\beta T_m-bT_mG_m}{2b} \tag{4}$$

Substituting the equation (2) in equation (3), and given w and T_s, I obtain the optimal solution of Tm:

$$T_m^*(w,T_s)=\frac{-ac\beta+bcw\beta-c^2T_s\alpha\beta-abG_m+b^2wG_m-bcT_s\alpha G_m}{-4bC_{tm}+c^2\beta^2+2bc\beta G_m+b^2G_m^2} \tag{5}$$

In addition, taking the Tm* into equation (4), and given w and T_s, the optimal solution is shown as:

$$p^*(w,T_s) = \frac{a+wb+c\alpha Ts}{2b} + \frac{(c\beta - bG_m)}{2b}\left(\frac{-ac\beta + bcw\beta - c^2T_s\alpha\beta - abG_m + b^2wG_m - bcT_s\alpha G_m}{-4bC_{tm} + c^2\beta^2 + 2bc\beta G_m + b^2G_m^2}\right) \tag{6}$$

Stage 2. Optimal solutions of the supplier

Assume that the supplier sets the wholesale price charged to the manufacturer w and green technology level T_s. The supplier has production cost C_s and green technology improvement unit cost C_{ts} to maximise its own profit. Thus, the objective profit function of the supplier will be:

$$Max \quad \pi_s(w,T_s) = (w - C_s + T_sG_s)\left(a - bp^* + c\left(\alpha T_s + \beta T_m^*\right)\right) - T_s^2C_{ts} \tag{7}$$

Substituting p^*, T_m^* which is obtained from the stage 1 into the supplier's objective function in equation (7),

$$Max$$

$$\begin{aligned}&(w - C_s + T_sG_s)\left(a - b\left(\frac{a+wb+c\alpha T}{2b}\right.\right.\\ &\left.\left.+\frac{(c\beta - bG_m)}{2b}\left(\frac{-ac\beta + bcw\beta - c^2T_s\alpha\beta - abG_m + b^2wG_m - bcT_s\alpha G_m}{-4bC_{tm} + c^2\beta^2 + 2bc\beta G_m + b^2G_m^2}\right)\right)\right.\\ &\left.+c\left(\alpha T_s + \beta\left(\frac{-ac\beta + bcw\beta - c^2T_s\alpha\beta - abG_m + b^2wG_m - bcT_s\alpha G_m}{-4bC_{tm} + c^2\beta^2 + 2bc\beta G_m + b^2G_m^2}\right)\right)\right) - T_s^2C_{ts}\end{aligned}$$

Subject to:

$\alpha + \beta = 1$, and $a - bp + c(\alpha T_s + \beta T_m) \geq 0$

Theorem 2. It is confirmed that a unique optimal solution exists, including the wholesale price and green technology level of the supplier. Also, the optimal solution maximises globally the supplier's profit in the supply chain model. See the proof of negative definition in Hessian matrix in Appendix 2.

Due to the word limitation of the paper, the optimal solution of the wholesale price and the green technology level for the supplier is presented in Appendix 3.

4.3 Results

With regard to the result chapter in the research project, the analysis of the mathematic game model is presented to state the influence of the incentive. There are two sections in this chapter; 4.3.1 is the sensitivity analysis of the game model, and it is followed by the investigation of the government incentive allocated strategy in section 4.3.2.

The sensitivity analysis is divided into three parts by the 3P concepts. In other words, I discuss the incentive influence through the three dimensions of people, planet, and profit. In the study, the sensitivity analysis is not only focused on the influence of each parameter on the decision variables, but also the extended decision variable which is product demand. Similarly, the study indicates the effect of the parameters a, c, α, β, C_s, C_{tm}, C_{ts}, G_m, G_s on the p^*, w^*, T_s^*, T_m^*, π_s, π_m and the demand. The sensitivity analysis is divided into three parts including (1) the influence of the incentive, (2) the influence of the market factors, and (3) the influence of the supply chain cost on pricing and green technology strategy, supply chain profit and product demand. The main focus will be (1) the influence of the incentive which is structured in Figure 6. Furthermore, the analysis of government green incentive allocation in the supply chain is also presented to understand the best incentive strategy for the government in 4.3.2.

4.3.1 Sensitivity analysis of the two-stage game model

I The influence of government incentive

The incentive on supplier and the incentive on manufacturer (G_s, G_m)

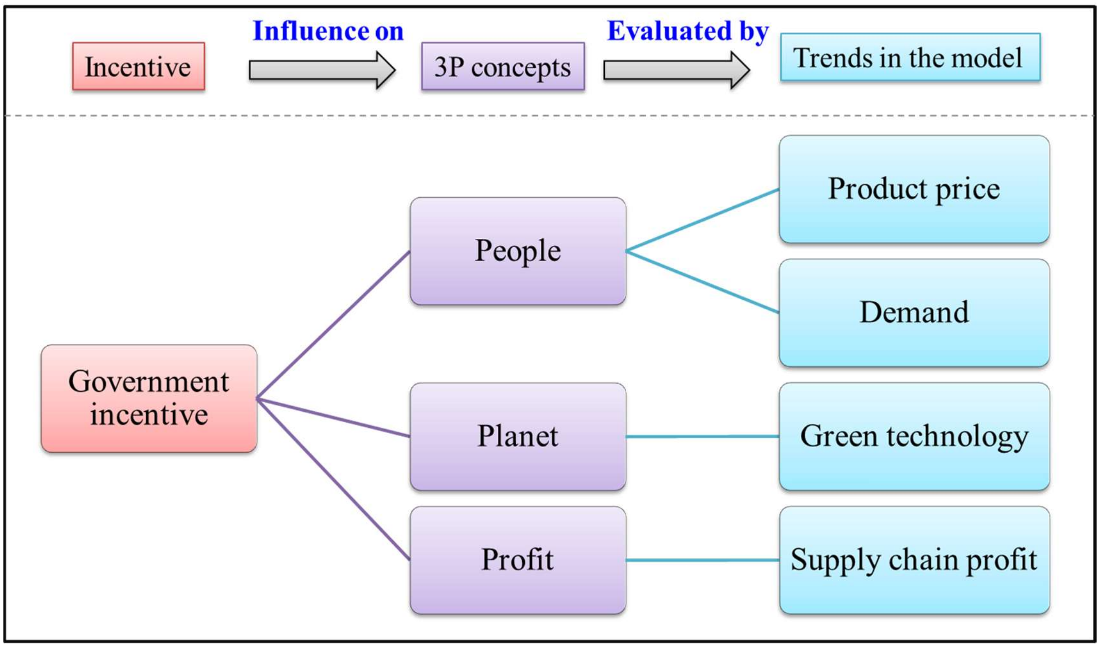


Figure 6 - The structure of government influence evaluation

In order to confirm the influence of government incentive on the supply chain, the market and the environment, I attempt to evaluate the concept of the 3P that contains planet, people and the profit as demonstrated in Figure 6. It is observed that the pricing strategy and market demand to understand the incentive effect on "people", which indicates the consumers in the market. Secondly, I analyse the green technology decisions of the supply chain to investigate the influence on "planet", and I consider whether the higher green technology improvement (less emission) has a positive influence on the planet. Thirdly, I investigate the "profit" concept through observing the supply chain profit trend as the incentive changes.

- **People:** Influence on market demand and the product price (p, *demand*)

Demand

It was found that the demand increases while the government provides more incentives on green products. The demand is affected by the green technology level and the product price. However, only the rise of green technology level is inflected on the product demand, the price is constant regardless of whether the government provides more incentives or not. Thus, the incentive does help to boost the green product demand by motivating the supply chain's characters to improve their green technologies; expected theme 1 is proved.

Product Price (p)

In the model, the incentive does not significantly affect the market price. In other words, the pricing decision of the manufacturer is not influenced by the amount of incentive given by the government. Although the manufacturer is in charge of setting product market price, neither the incentive on the supplier nor the manufacturer have any significant influence on the manufacturer's product pricing strategy. To conclude, market price is not significantly affected by government incentives from either supplier's or manufacturer's side.

- **Planet:** The influence of the incentive on supply chain green technology (T_s, T_m)

To investigate the incentive's impact on the planet, the change of green technology is presented. Figure 7 and Figure 8 represent the green technology level of the manufacturer and the supplier while the government provides different incentive rates to the supplier. It is confirmed that the incentive to the supplier can enhance their own green technology level, hence, expected theme 2 is confirmed in an agreement. For the supplier, the more incentive they receive, the higher green technology level will be achieved to maximise the profit. However, the supplier's incentive rate does not significantly affect the manufacture's green technology level. Only when the incentive rate is within certain low range and certain high range, a positive effect of the incentive on manufacturer's green technology decision is in existence. This can be explained by that the manufacturer would not be driven by the supplier's incentive to invest in green technology unless their own's cost of technology innovation is covered by the profit generated by the increased demand. However, the manufacturer would not continue the green technology innovation unless the supplier's incentive rate reaches nearly its maximum and at the same time the supplier makes great effort in green technology innovation. In this case, both the supplier and the manufacturer will increase their green technology level.

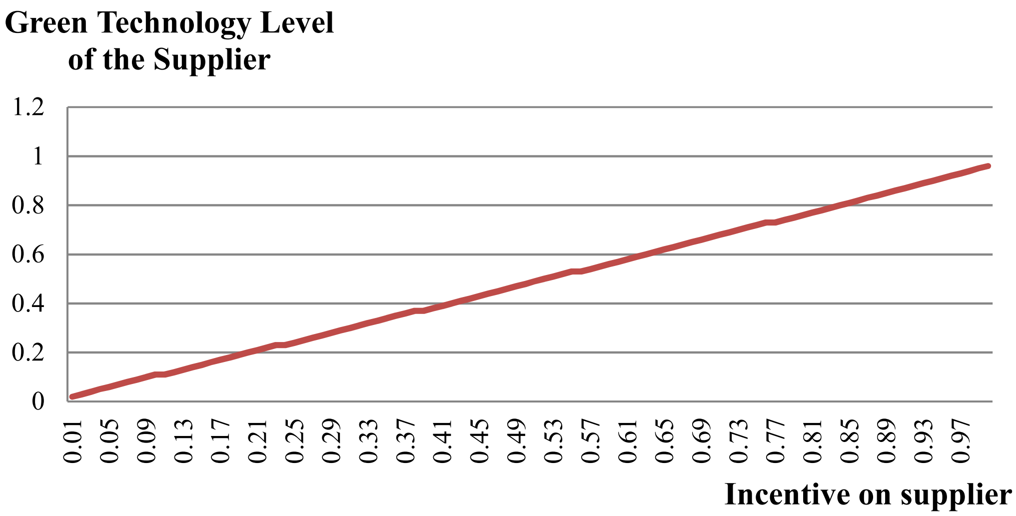


Figure 7 - The influence on its green technology level of increasing the supplier's incentive

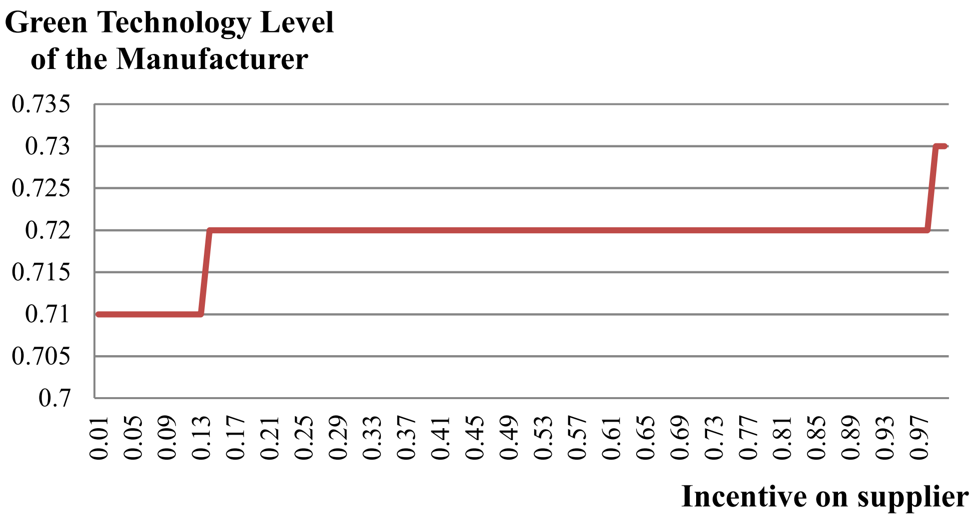


Figure 8 - The influence on the manufacturer's green technology level of increasing the supplier's incentive

Figure 9 and Figure 10 show the case of providing different incentive rates to the manufacturer. It is confirmed that the manufacturer's incentive can enhance their own green technology level which confirms the expected theme 2. The manufacturer's decision of the green technology level is also followed by the incentive rate, and they have a closely linear relationship. Based on the 4 figures above, it can be found that the influence of supplier's incentive and manufacturer's incentive on supply chain green technology decisions are different, thus expected theme 4 is confirmed.

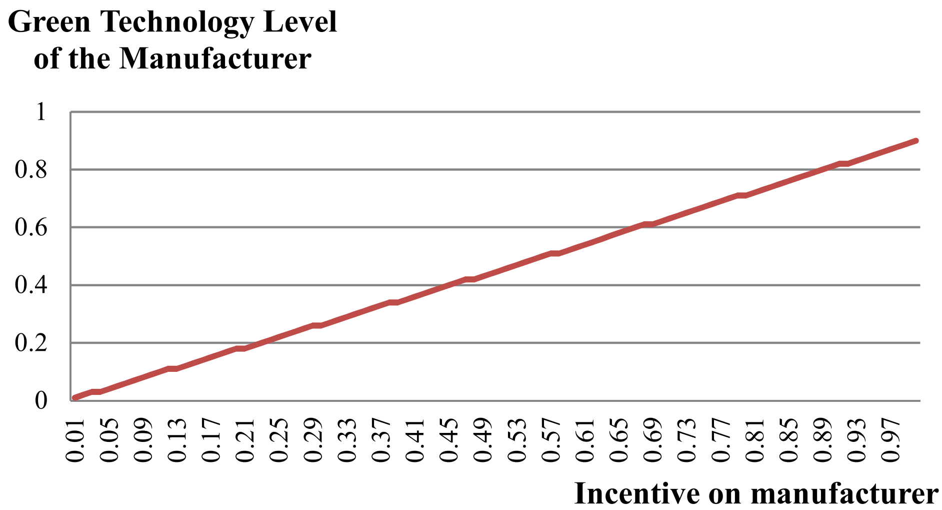


Figure 9 - The influence on its green technology level of increasing the manufacturer's incentive

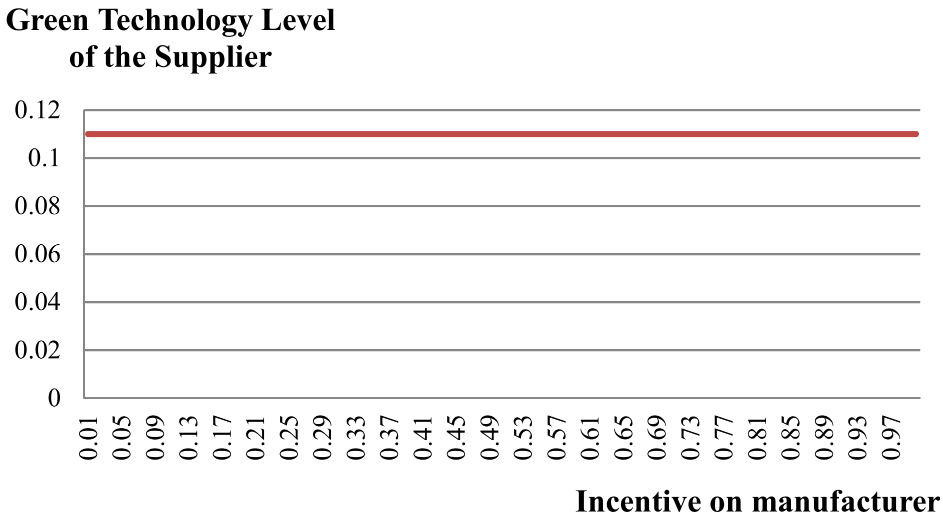


Figure 10 - The influence on the supplier’s green technology level of increasing the manufacturer’s incentive

Further, the study identifies the difference of the incentive’s influence of the two supply chain parties. It is remarkable that the incentive has more influence on the supplier than on the manufacturer. That means the efficiency of the incentive on the supplier and the manufacturer is different. Thus, expected theme 4 is verified and confirmed. Specifically, the result shows that the government giving an incentive to the supplier can increase the green technology level of the supplier itself as well as the manufacturer (Figure 7 and Figure 8). However, when the manufacturer incentive is raised by the government, only the manufacturer’s green technology level improves instead of both the manufacturer’s and the supplier’s. The supplier’s green technology strategy is not influenced by the amount of incentive given to the manufacturer.

➢ **Profit:** The incentive influence on the supply chain profit (π_s, π_m)

With regard to profit in the supply chain, it is verified that incentive is positively related to the profit by the adoption different values of the incentive in the model. Figure 11, Figure 12, Figure 13, and Figure 14 show that the trend of the profit rises when the government increase the incentive rate. The marginal profit of the product selling increases with the incentive rate, thus the total profit of each party is expected to become higher when they receive incentives from the government.

Both the manufacturer and the supplier receive a benefit on the profit when they have more financial intervention from the government. However, it is notable that the improvement of the profit for the supplier is more significant than for the manufacturer. Namely, the supplier, as a leader in the game model, gains more financial advantage than the manufacturer from the incentive. Moreover, the study proves that the incentive is positively related to the profit of the manufacturer and the supplier, which supports expected theme 3.

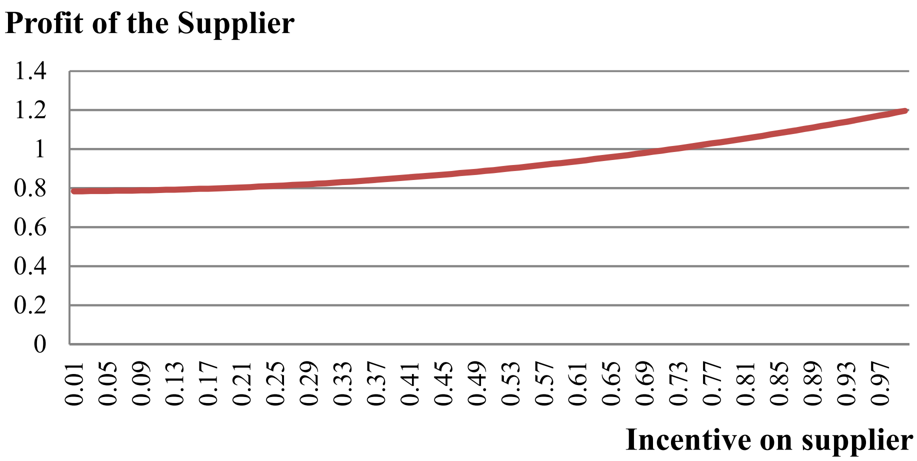


Figure 11 - The influence of increasing the supplier’s incentive on its profit

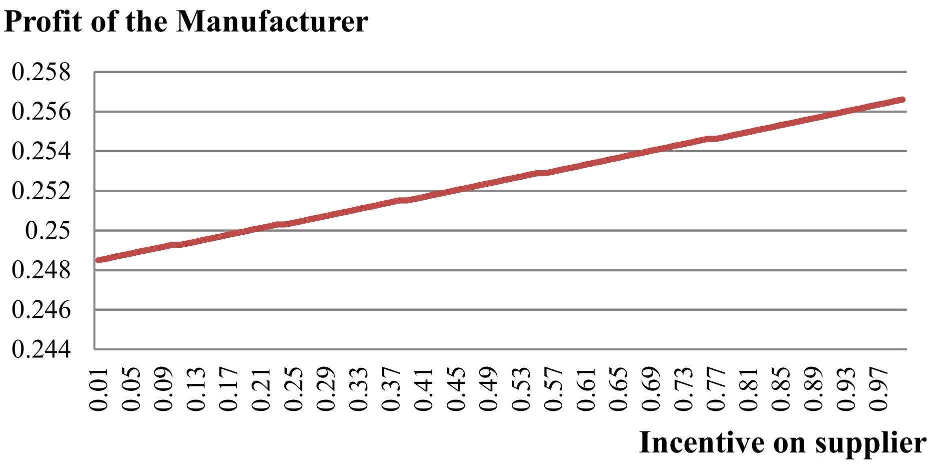


Figure 12 - The influence on the manufacturer's profit of increasing the supplier's incentive

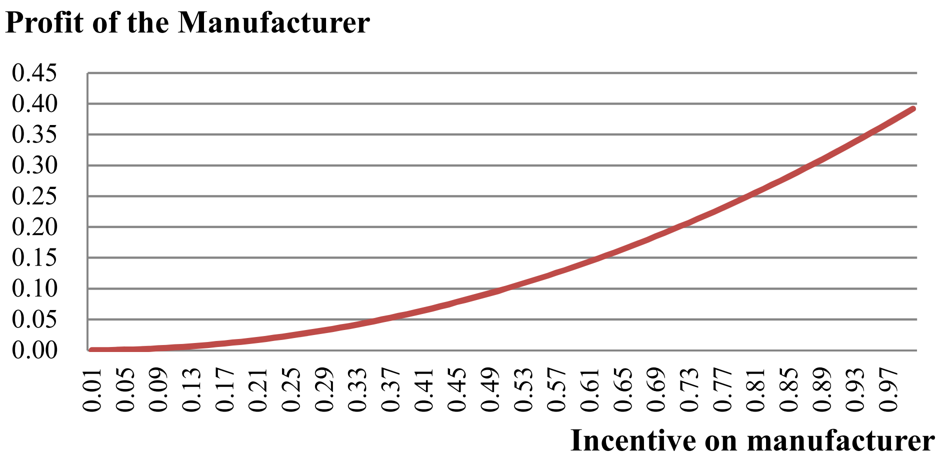


Figure 13 - The influence on its profit of increasing the manufacturer's incentive

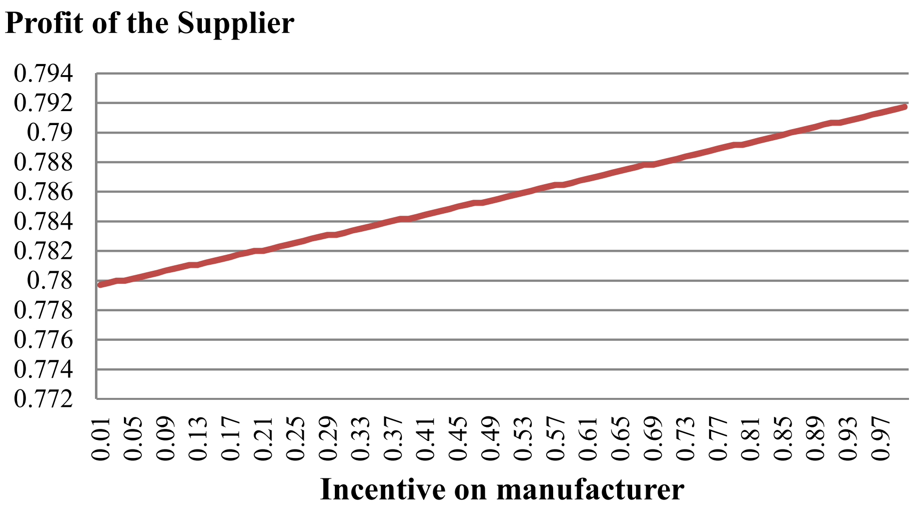


Figure 14 - The influence on the supplier's profit of increasing the manufacturer's incentive

Lastly, with regard to expected theme 5, the study also illustrates the change of the pricing strategy through giving various values to the parameter of the incentive. From the observation of pricing decisions including wholesale price and the product price in the market (w, p), it is proven that pricing decisions are not affected by the government incentive. That is, the supply chain does not respond to the incentive by changing the prices. The wholesale price and the product price are constant despite whether the government offers more incentive to either the supplier or the manufacturer. When the incentive has made a change, the supply chain roles tend to respond by altering the technology decision instead of pricing.

II The influence of the market factors

The green product market size, the effect of the green technology level on demand, the weight of the supplier's green technology relating to the demand, and the weight of the manufacturer's green technology related to the demand (a, c, α, β)

- **Market size**: a

Market size plays an important role in that it influences the product demand and profit in the model. The sensitivity analysis indicates that the size of the green product is positively related to the demand, the profit of the manufacturer and the supplier. Moreover, the response of the supply chain to the green technology level is also affected by the market size. When the market scale becomes larger, that indicates profitability, and the supplier and the manufacturer are more likely to invest their green technologies. Figure 15 and Figure 16 present the reaction of the manufacturer and the supplier under the different values of the market size. The manufacturer closely follows the market size to increase the green technology level as shown in Figure 16. However, this phenomenon does not appear on the supplier side. The supplier improves the technology discretely as the incentive increases in Figure 15. The reason of the ladder-sharp trend of the green technology level is caused by the supplier, who can only be motivated by certain amounts of increase to the incentive.

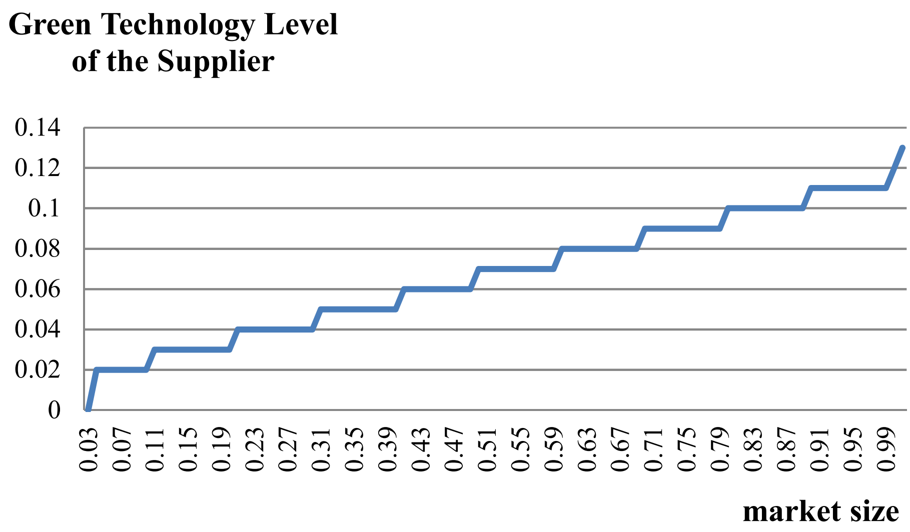


Figure 15 - The influence of the market size on the green technology level of the supplier

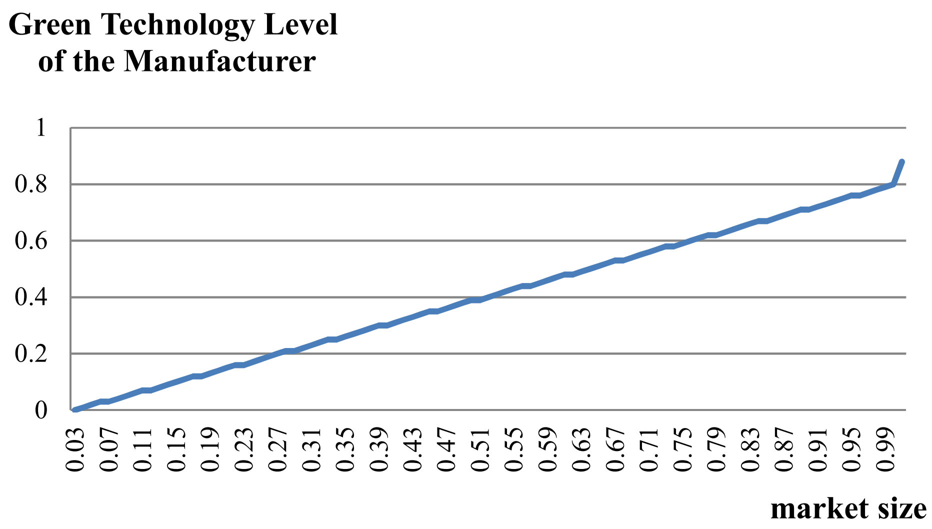


Figure 16 - The influence of the market size on the green technology level of the manufacturer

- **The influence of the green technology level on demand**: c

In the model, it is assumed that there is a constant representing how much the green technology level influences the demand. The effect can be considered as the importance of the green technology level for the consumers in the market. If the consumer's willingness to buy the product is extremely dependent on the green level, the green technology of the product has a significant relationship with the demand. First point, the higher importance of the green level for the consumer results the more demand and profit in the supply chain. Moreover, under different cases of the parameter setting, all the technological decisions are affected by the importance of the green level for the consumer. To be more specific, the supplier is willing to improve the green technology level when consumers take "green" as an influential factor, as shown by the trend in Figure 17. It is notable, however, that the manufacturer does not react in the same way as the supplier. When consumers show their preference of the "green", the manufacturer responds by changing the green technology level only under certain situations. That is, if the influence of the green technology on the demand is less than a critical value that is shown in Figure 18, the manufacturer will enhance the green technology to fulfill the consumer's need. However, in most cases, the manufacturer does not base their technological decisions on the influence of the green technology on demand.

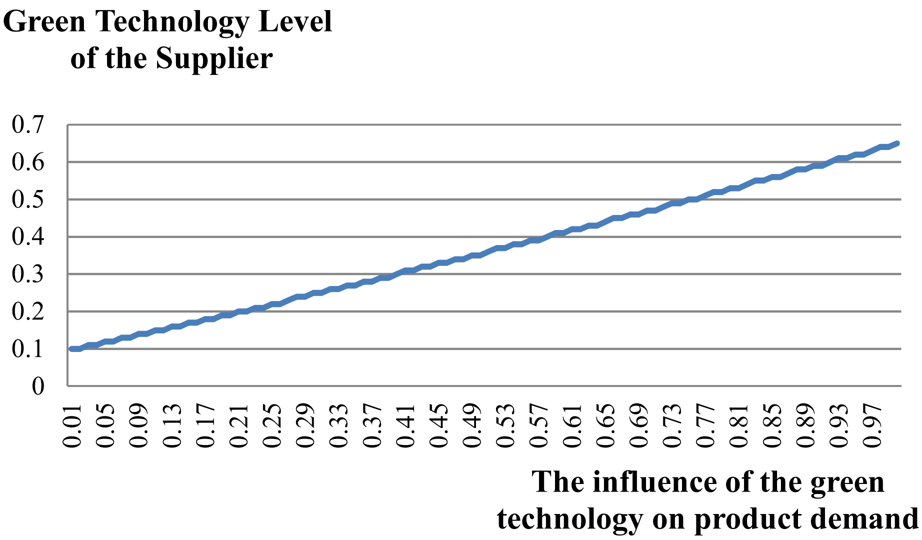


Figure 17 - The relationship between the green technology level of the supplier and the influence of the green technology level on demand

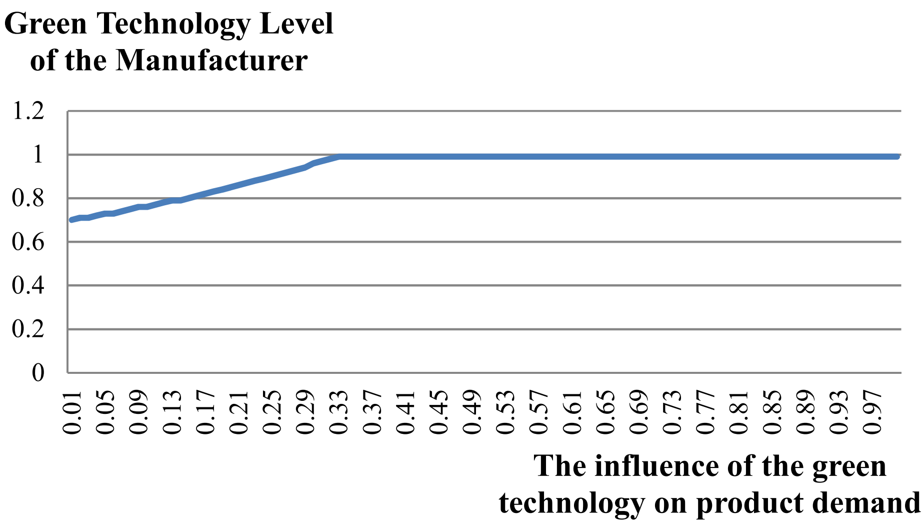


Figure 18 - The relationship between the green technology level of the manufacturer and the influence of the green technology level on demand

- **The influence of the weight of supplier's and manufacturer's green**

technology on the demand: α , β

In the two-stage game model of the study, the green technology level of the supply chain is one of the factors leading the product demand. The weight means the percentage of the supplier and the manufacturer affecting the demand. If α equals 1, that indicates that the supplier's green technology level is in charge of affecting the demand. Further, $\alpha = 0.5$, $\beta = 0.5$ means the supplier's and the manufacturer's green technology are equally related to the demand. From the sensitivity analysis of the parameter, the study points out that the weights of the supplier and the manufacturer are associated with the decision-making process of the model. It is remarkable that when the green technology is more supplier-driven, there is a negative effect on the overall demand and the profit of the supply chain. Similarly, as consumers care more about the supplier's technology and the willingness to buy the product is based upon that, there is a negative effect on the demand and the profit. As the supplier holds more power over influencing the demand, the optimal decision of the green technology of the supplier will rise and the manufacturer's will decrease. See Figure 19 and Figure 20 below.

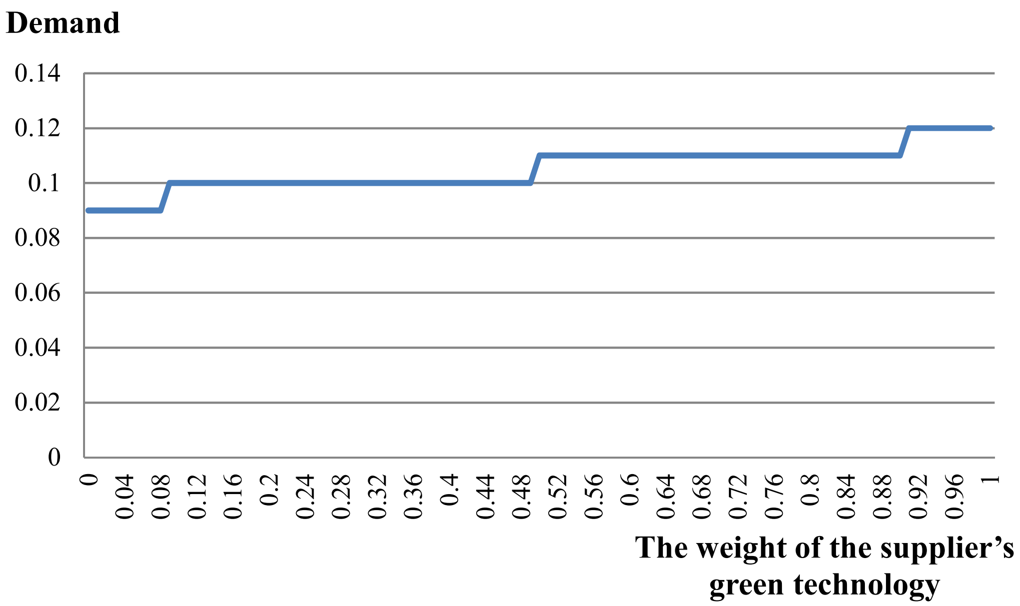


Figure 19 - The weight of the supplier's green technology related to the demand

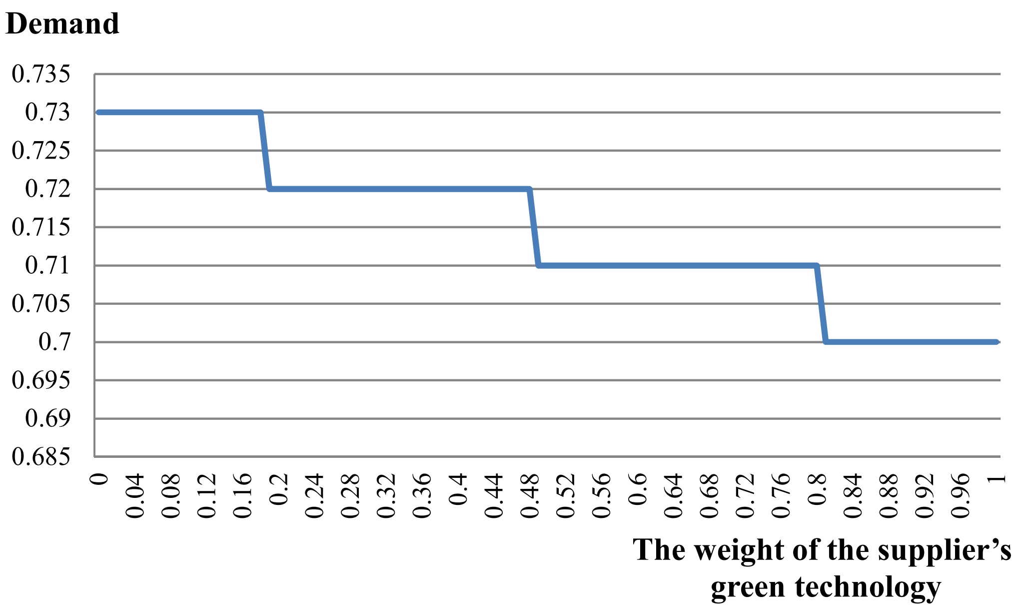


Figure 20 - The weight of the manufacturer' green technology related to the demand

III The influence of the supply chain cost

The cost of the raw material for the supplier, the marginal cost of increasing green technology for the manufacturer, and the marginal cost of increasing green technology for the supplier (C_s, C_{tm}, C_{ts})

To compare the effect of those cost factors in the game model, various values of parameter setting are conducted. All the costs of the supplier and the manufacturer lead to lowering the demand and profit, and make no change to their pricing strategy. Demand and profit decrease as cost rises. At the same time, however, the wholesale price and the product price are constant while costs change. This means that to maximise the profit, the supply chain characters would need to adopt a new green technology strategy in order to respond to the cost differences rather than achieving that through pricing strategy. The supplier's cost involves raw material cost and marginal green technology cost. It is straightforward that raw material cost decreases the optimal green technology level of the supplier and makes no change to the manufacturer. Next, the marginal green technology cost of the supplier is negatively associated to the optimal green technology of both parties as shown in Figure 21 and Figure 22. As a result, the supplier's marginal cost of the green technology plays an important role that negatively affects the whole supply chain's green technology level. Further, the marginal green technology cost of the manufacturer is not as influential as the marginal green cost of the supplier.

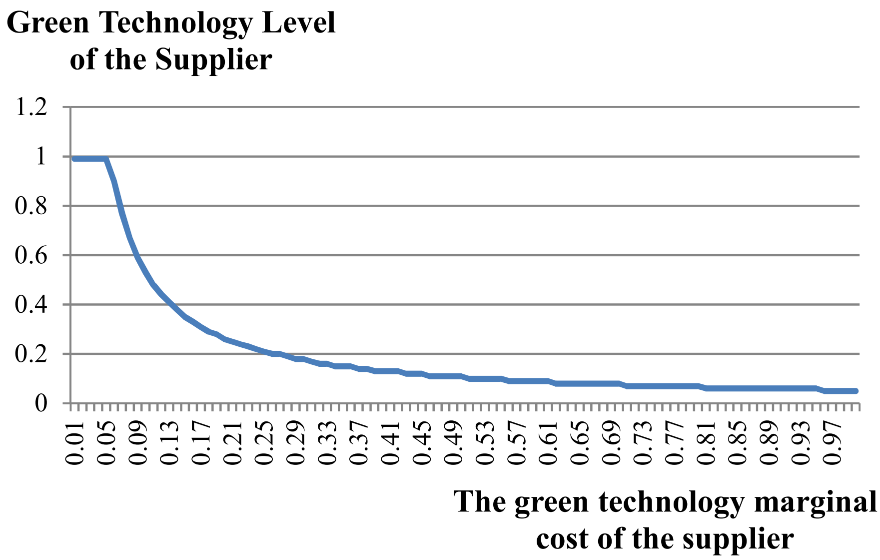


Figure 21 - The influence on its green technology decision of the green technology marginal cost of the supplier

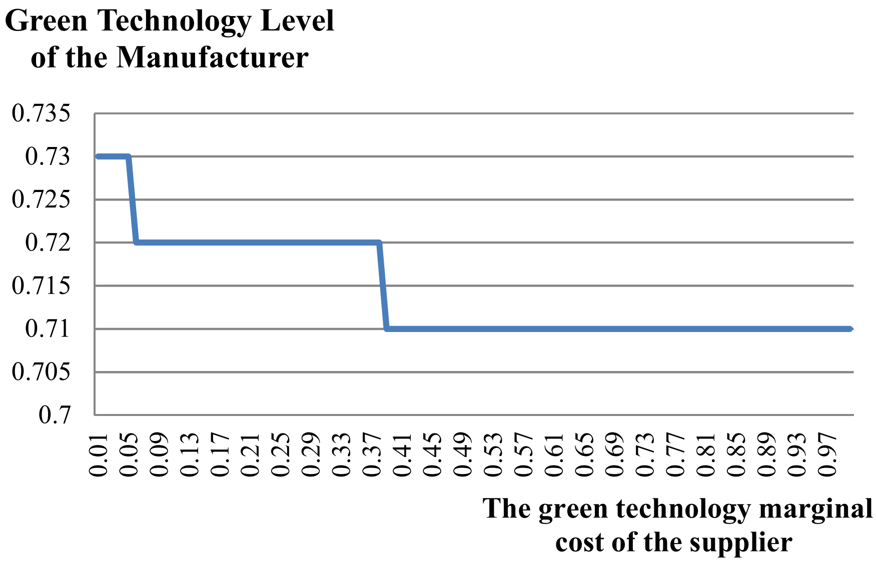


Figure 22 - The influence on the manufacturer’s optimal green technology level of the green technology marginal cost of the supplier

4.3.2 Incentive allocation on the supply chain

This section discusses the proportion of providing incentive to the supply chain. To investigate the best incentive strategy for the government, the study compares three different ways of allocating incentive to the supplier and the manufacturer. Firstly, this section presents the trend of the profit and the green technology level of supply chain's characters when the government provides equal incentive to the manufacturer and the supplier. In other words, the supplier and the manufacturer receive the same amount of incentive $G_s = G_m$. This is then followed by the example of the government giving a higher percentage of incentive to the manufacturer. In contrast, the case of the supplier holding more green incentive from the government will also be discussed.

I Incentive Divided Equally

The manufacturer and the supplier receive the same amount of incentive from the government

When the government incentivises equally the manufacturer and the supplier, the figures show that both their profits increase exponentially as the incentive rises. Also, when the government's financial support is the same for both sides, the amount of profit increase is approximately equivalent. That means that in this case the green supply chain's roles share the benefit from the government.

$G_m = 1, a = 0.9, b = 0.03, c = 0.03, C_{ts} = 0.5, C_{tm} = 0.5, C_s = 0.1, \alpha = 0.5, \beta = 0.5$

Manufacturer's profit

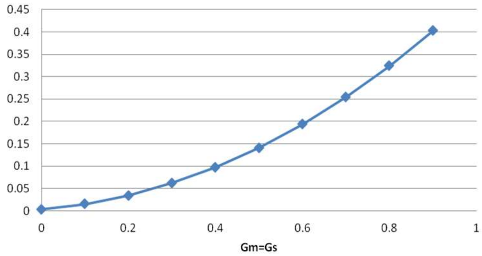


Figure 23 - Manufacturer's profit based on different incentive rates (incentive divided equally)

Supplier's profit

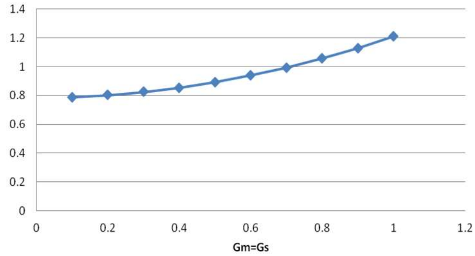


Figure 24 - Supplier's profit based on different incentive rates (incentive divided equally)

It is confirmed that the manufacturer and the supplier's decision of green technology level is affected by the government's incentive policy. Higher incentive can encourge the supply chain to improve the technology so that the green level of the product increase.

II Manufacturer Focused

The manufacturer receives more incentive than the supplier from government

From the modeling result, it can be observed that both the manufacturer and the supplier's profit increases when the government offers more incentive to the green product. For the manufacturer, the more the incentive the higher the profit. Also, the supplier has a positive increase when the government provides more incentive. It is notable that profit rises slightly under a small amount of incentive but significantly when the incentive reaches a certain value.

$G_m = 1, a = 0.9, b = 0.03, c = 0.03, C_{ts} = 0.5, C_{tm} = 0.5, C_s = 0.1, \alpha = 0.5, \beta = 0.5$

Manufacturer's profit

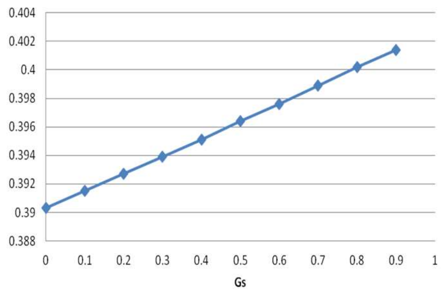


Figure 25 - Manufacturer's profit based on different incentive rates (manufacturer focused)

Supplier's profit

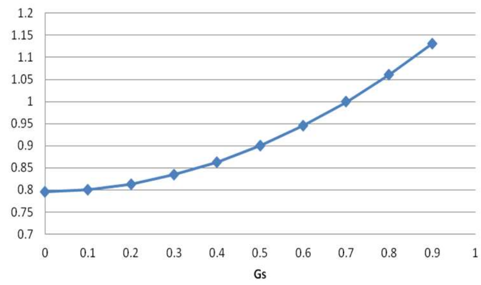


Figure 26 - Supplier's profit based on different incentive rates (manufacturer focused)

Under the scenario of manufacturer focused incentive strategy, incentives can help to improve the manufacturer's green technology level. In terms of the supplier, nevertheless, only the incentive rate locates between certain ranges can increase their green technology level. That is, when the incentive rate becomes too low or too high, the increase in incentive rate has no significant positive effect on supplier's green technology level. A possible explanation of the effect is that the supplier only invests in green technology when the incentive rate breaks even with the technology cost. However, beyond the breakeven point, supplier will not continue to invest even when incentive rate increases, because the investment does not have any positive effect on profit. In addition, the overall increase in the supplier's green technology level is not as much as that of the manufacturer. Manufacturer focused incentive strategy can encourage more green technology improvement from manufacturer's side and much less from supplier's side, because most of the incentives are provided to the manufacturer, and the supplier is thus not motivated to invest in green technology innovation.

$$G_m = 1, a = 0.9, b = 0.03, c = 0.03, C_{ts} = 0.5, C_{tm} = 0.5, C_s = 0.1, \alpha = 0.5, \beta = 0.5$$

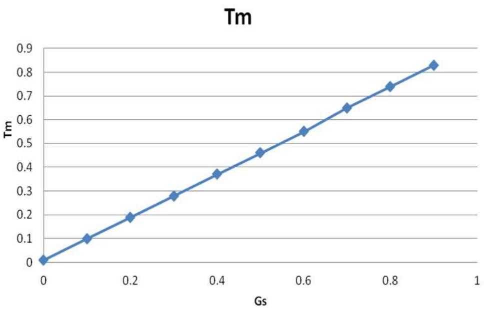


Figure 27 - Manufacturer's green technology level based on different incentive rates (manufacturer focused)

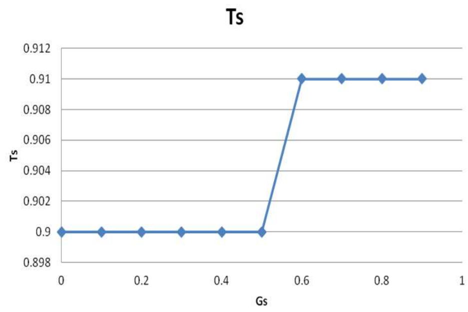


Figure 28 - Supplier's green technology level based on different incentive rates (manufacturer focused)

III Supplier Focused

The supplier receives more incentive than the manufacturer from the government

When the supplier has a higher percentage of the government's incentive, the profit trend is different to when the manufacturer holds more incentive. The larger the incentive, the better the profit for both the manufacturer and the supplier. When the government increases the financial support, the supplier's profit grows linearly. However, the profit of the manufacturer rises exponentially as the incentives increase.

$$G_s = 1, a = 0.9, b = 0.03, c = 0.03, C_{ts} = 0.5, C_{tm} = 0.5, C_s = 0.1, \alpha = 0.5, \beta = 0.5$$

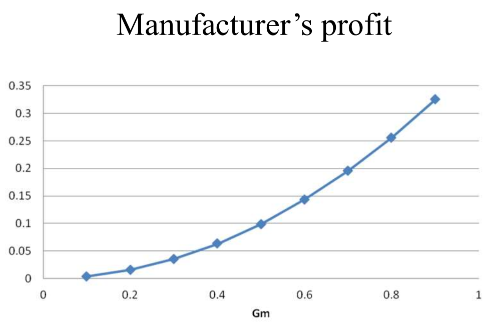


Figure 29 - Manufacturer's profit based on different incentive rates (supplier focused)

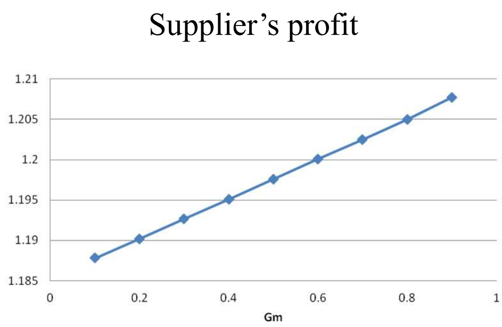


Figure 30 - Supplier's profit based on different incentive rates (supplier focused)

Compared to the Manufacturer focused type, the green technology decision of the supplier has the same impact as the increase of the incentive in the Supplier focused type. That is, except when both parties share the incentive equally, the influence of the incentive on green technology trend is the same in both the Manufacturer focused and the Supplier focused case.

4.4 Summary of the Findings

Firstly, market demand can be promoted by increasing government incentive; however, the market price stays the same while demand increases. A reason for this phenomenon is that the supply chain parties' willingness of investing in green technology is enhanced by the incentives. Incentives increase the profit of the green product and also lead the supply chain parties to improve their green technologies. Thus, the influence of incentives on people (market and consumers) is confirmed, and a positive impact is demonstrated.

It is noteworthy that the incentive to the supplier can drive the whole supply chain to having a better level of green technology of the product. The financial intervention on the manufacturer can only motivate itself while the supplier remains unaffected. Moreover, both the manufacturer and the supplier have higher profits when they have more financial intervention from the government. However, the improvement of the profit is more significant for the supplier than the manufacturer, meaning that the supplier gains more benefit when the government incentivises green technology in the supply chain.

Due to the supplier not interacting with the market directly, while the manufacturer does, the supplier's response to the change of market size is not as sensitive as the manufacturer's. If the consumer's preference is highly based on the green degree of the product, however, the supplier will improve its own green technology level in order to generate more demand. However, the manufacturer is rarely motived to make technological decisions by the consumer's preference.

4.5 Conclusion and Discussion

Preliminary Study 1 has verified the influence of the government incentive on supply chain decisions. It has been found that the government's incentives can affect the decisions making process of the supply chain. Providing financial support does drive the supplier and the manufacturer to expand the green technology of the production. Incentive, furthermore, has a positive effect on supply chain green technology level, supply chain profit, but limited effect on the product market price.

In relation to the literature, the study confirmed the results of previous studies (Sheu & Chen, 2012; Jin et al., 2011) that green product incentive is positively related to environment friendliness and to the supplier's profit. Offering incentives to the supplier and the manufacturer is a way of promoting green products to the market.

Apart from the fact that incentives can motivate supply chain roles to enhance their green technologies, incentives also have a positive impact on product demand and they can increase supply chain profit. However, it is notable that a green supply chain only responds to the increase of incentives by reaching a different green technology level. Pricing (as another decision variable) strategy is not affected significantly by the incentives. In other words, the wholesale price of the supplier, and the product price of the manufacturer do not change gradually when the incentive increases. In summary, the supply chain tends to rise the green technology level when it is profitable to implement. Neither the supplier nor the manufacturer would adjust their pricing strategy to react to the government's incentive on a green product.

Furthermore, the impacts of the incentive on the supplier and the manufacturer are compared, with an aim to assess the differences between their responses. The results have suggested that the government should offer more incentives to the supplier than to the manufacturer, precisely because, when the government provides financial support to the supplier, the incentive can encourage both the supplier and manufacturer at the same time, to improve their green technology. In contrast to incentivising the supplier, manufacturers' incentive is only positively related to the manufacturer's green technology degree and it does not affect both. For this reason, the government should increase its allocation of incentives to the supplier to stretch further a limited budget**.**

Chapter 5: Preliminary Study 2: Qualitative empirical research

5.1 Introduction

This study attempts to gather evidence-based information to understand the decision making in the supply chain given government incentives. The results of this enquiry will be used to verify and adjust the assumptions of the mathematical model in Main Study 3. The literature indicates that the qualitative method is used to explain humans behaviour, help seek the reason behind this behavioural phenomenon, or have a better, detailed understanding of the practice. In this project, Study 2 is designed to capture practical information in the car industry in terms of supply chain operations and government green incentive mechanisms. A semi-structured interview is employed to obtain a better understanding of practice in the car supply chain. It is indicated in the study of Palinkas et al. (2011), that a mixed method design is more appropriate in implementation research than either qualitative or quantitative approach alone because their combination brings richer information of the focused research issues. In the mixed method design, quantitative method is often used to examine and test a hypothesis based on a conceptual research framework. In this study, the qualitative method is used to access practical evidence from the supply chain in the car industry to support the formulations and assumptions of the mathematical model in Main Study 3.

5.2 Method

i. Context of the study

Taiwan is chosen to collect the qualitative data in Preliminary Study 2 for two reasons. Firstly, this study aims to understand the decision making in car supply chain based on the government incentive project. Taiwanese government does provide various type of incentive to supply chain, five government departments work together toward to green technology development of green cars in the supply chain. Not only the government actively offers incentives to supply chain, but car supply chain parties also have the willingness to participate in incentive projects. As a result, most of car supply chain parties in Taiwan have experience in participating in government incentive projects. Thus, the decision making in car supply chain in Taiwan is suitable to be investigated in Preliminary Study 2. Secondly, to manage the problem of carbon emissions from transportation, the Taiwanese government has focused on incentives on green technology innovation and pay less attention to disincentives. This reduces the bias of the influence of disincentives on green technology development in car supply chain.

However, the scale of the green car market in Taiwan is not as big as other countries such as China and U.S. which indicates it is less competitive between product providers. Although there is no evidence suggests the government's incentives have more influence on supply chain behaviour in a larger scale of markets than smaller ones. The number of supply chain parties available to be interviewed in Taiwan is fewer than in a bigger scale of the country. The collected data may reflect less information due to the small market scale which is considered as a limitation. To reduce the impact of the limitation to the research findings, in Preliminary Study 2, all of the car companies who do manufacture in Taiwan have been interviewed which ensured the completeness of collected information.

ii. Sampling and target companies

In Preliminary Study 2, the non-probability sampling approach is selected which is normally applied by qualitative studies. In this study, the collected data is used to fill the lack of information for the establishment of the mathematical model in Main Study 3. Capturing accurate information necessary for the project is more important than seeking a large sample size (Jankowicz, 2005). The objective of the present study is to investigate and collect evidence-based practical information from car supply chain parties, and that is why specific interviewees are targeted. Because it is commonly used to identify the samples that may have rich information regarding the research interest and propose, purposive sampling is adopted in this study (Palinkas, et al., 2015).

Because Study 2 attempts to collect practical information from the supply chain, particularly in the car industry, car supply chain parties have been selected to be interviewed. The two main parties in supply are the supplier and the manufacturer, in addition to whom an additional interviewee has also been selected. This interviewee is a government officer who has six years' experience in government green incentives projects in the Taiwanese car industry. There are ten interviewees from the car supply chain altogether and one from government green incentive. To obtain the information needed for the research, it is important to identify the appropriate interviewees from the car industry. In this study, selected participants were from the R&D department, the green technology development associated team, and managers from product design and the innovation department. They are selected because green technology innovation is managed by them in the company, and they are familiar with green technology decision making. Having been closely involved in the incentive project, they also possess the knowledge concerning the interactions between companies and the government in the incentive project. Hence, it is believed that all the selected interviewees are appropriate informants for the research.

The following table shows green car companies in Taiwan and the selected companies in the interview, if they do manufacturing in Taiwan, and whether their suppliers and manufacturers are included in the interview.

Table 3 - Selected interviewees in Preliminary Study 2

Brand/ Company	Do they do manufacturing in Taiwan?	Selected in Interview	Number of Interviewees	
			Manufacturer	Supplier
TOYOTA	Yes	Yes	1	1
LEXUS	Yes	Yes	1	1
Yulon-Nissan	Yes	Yes	1	1
Luxgen	Yes	Yes	1	1
Volvo	No	Yes	1	0

BMW	No	Yes	1	0
Government Officer	N/A		1	
Total number of interviewees	N/A		11	

Personal interview has been used because it can generate more insightful data than other data collection techniques (Robson, 2002). Especially for sensitive information such as supply chain decisions, government funding and incentives project details, personal interview is a more effective tool compared to questionnaires (Millington et al., 2005). Thus, a personal interview has been adopted in Study 2.

iii. Access to participants

In the purposive sampling, the interviewer is required to have some degree of access to the targeted interview participants. In this study, access to interview participants has been gained through personal contacts in the car industry and the relevant government departments in Taiwan as the author of this thesis is funded by the Taiwanese government.

iv. Unit of analysis

The unit of analysis is important for qualitative research. The analysis unit should be small enough to be considered as the "meaning unit" for the data analysis (Graneheim & Lundman, 2004). It has been defined as the unit of collected data which is analysed in the project, and it is suggested that a study should have a suitable unit of analysis corresponding to the research problem (Collis & Hussey, 2003). This study aims to explore supply chain behaviour in the car industry, with the suppliers and manufacturers (main supply chain characters) as the targeted roles which have their own companies' independent information. Thus, the supply chain party is selected as the unit of analysis.

v. Data collection

Interview data were collected through face-to-face interviews at car supply chain companies. Participants were from the R&D department, the green technology development associated team, and managers from product design and the innovation department. The following section explains the reasons for choosing the semi-structured interview to collect qualitative data in this study.

This project aims to collect rich information regarding the supply chain practice in the car industry, and both unstructured interviews and semi-structured interviews allow interviewers to obtain rich data. Notably, a semi-structured interview can not only help researchers to collect detailed and rich information from interviewees but also to remain focused on key research topics (Saunders et al., 2007). As the objective of gathering qualitative data in this study is to confirm and verify the structure of the model in Main Study 3, it is necessary to remain focused on the interview questions. Hence, a semi-structured interview is considered as a more appropriated approach for this study than the method of unstructured interviews.

In the semi-structured interviews, interview questions are pre-determined, and their order is sorted systematically and consistently to encourage participants to develop their ideas (Berg, 2004). The order of questions is designed to help guide participants' thinking: following a list of questions and sub-questions that rich information is revealed. In addition, the semi-structured interview has a better focus on central issues during the interview because the interview questions are predetermined. Except for the existing components in the model, unexpected information from the interview may also be valuable for the model as it can be used to adjust and modify its components and assumptions. Thus, the semi-structured interview is selected in this study for its flexibility of gathering rich and insightful information but also for keeping in focus predetermined central issues that help participants to develop their thinking and ideas.

When a research project is involved in highly confidential or commercially sensitive issues, a semi-structured interview is a suitable data collection method (Easterby-Smith, Thorpe, & Lowe, 1991). In this study, it is determined that information of the car supply chain operation, supply chain behaviour, and the influence of incentive on supply chain decisions are aimed to be collected. For example, supply chain parties are asked the production and pricing decisions which are considered as sensitive information for companies. Thus, the semi-structured interview has been chosen to gather the required information from the interviewees.

vi. Interview guides

The semi-structured interviews were processed according to the instructions in the interview guide in this study which is presented in Appendix 5. The quality of the semi-structured interviews can be ensured when a clear interview guide is followed, and for this reason, an interview guide was prepared before the start of interviews. Having the interview guide, the interviewees will have a better understanding of the professional terms that appear in the interview questions.

There are two sections in the interview guide. Before the start of the interview, the first section is read to the interview participants. This section includes the research background and the interviewer's background, research procedure and the agreement of confidentiality. The second section is also read to the interview participants during the interview. This includes the content of interview questions that are pre-determined and have covered all the research issues in this study.

vii. Interview questions development

In this study, there are 9 leading central questions and 21 sub-questions (prompt questions) in the interview questions. Firstly, 9 leading central open-ended questions were developed depending on the key components, the assumptions of parameters' setting in the simulation model in Main Study 3 which was required to be confirmed. There are 6 main categories in the leading interview questions: government incentives, green technology issues, green car supply chain operations, the market demand trend, and emission trade. Secondly, 21 sub-questions based on 9 central questions were added to help capture richer information. These sub-questions were extended from the central questions which can help guide the participants to answer the questions comprehensively and widely. The interview questions for suppliers and manufacturers cover the same topics, yet with different focuses. For example, green technology development questions for supplier focus on the green degree of the key components such as the green design and use of materials in the motor and battery. Green technology development questions for manufacturer focus on the design of car integration system and the design of the vehicle power system. The concept of emission trading is also introduced to interviewees before asking questions: “Emission trading is the trade of permitted emissions between different parties. The government determines the emission obligation of the participating parties, and the unused permitted emission unites can be traded with or sold to other parties” . The following table shows the connection between pre-determined interview leading and prompt questions and expected evidence-based implications to be used in the model in Main Study 3. Interview questions for suppliers and manufacturers are presented in Appendix 6.

Table 4 - Interview questions and corresponding issues in the mathematical model

Interview questions	Corresponding research issues
1. What was the best-selling green car in your company in the past five years? P1. Why do you think this model could become a best seller? P2. What role do you think the government has played when you promoted this model?	■ Practice evidence: Background case of the green vehicle which fits the incentive model ■ Government's intervention in green cars' market promotion
2. When your company delivers the green car marketing strategy, which factors of the car do you think influence most consumer preferences? P1. Can you give me an example of the car model and its sales? P2. Why do you think these factors affect consumers' choices?	■ Key factors which affect market demand (consumers choices) ■ The relationship between the relevant factors and the car demand
3. Can you describe what factors your company considers when developing a new green model? P1. Can you give an example? P2. What are the issues you consider during the process? P3. What are the main reasons stopping/driving your company from/toward green technology	■ Supply chain decisions in green car production ■ Supply chain strategies for green technology development ■ The objective of the manufacturer and the supplier ■ Motivations and the barriers in green technology innovation

Interview questions	Corresponding research issues
innovation?	
4. Which roles in the car supply chain do you think are relatively influential for green vehicle green technology development? P1. Why do you think so? P2. Can you give me an example?	■ Supply chain parties involved in the decision of final car greenness
5. Which key production processes/components are highly relevant to a green vehicle's green technology? P1. Why do you think so? Does your company have any problems accessing these key components? P2. Which parts of the ones that you have described account for most of the production cost?	■ Key production processes and car components relate to green technology ■ The sources/supply of these key components and the costs
6. Following the previous question, do the government's incentives affect green car design in your company? P1. If yes, can you describe how government policy affects the car design? P2. If no, does tax/emission penalty or any other government policy impact on the green technology design?	■ Current incentives on green cars provided by the government in car supply chain ■ The impact of tax and emission penalty related policy on the green technology development of green cars
7. Has your company received any	■ Example of incentive project in car

Interview questions	Corresponding research issues
government incentives/funding for green technology development? P1. If yes, can you provide an example? P2. If no, did your company try to apply, and what was the reason for the failure? P3. Do you know any of your upstream/downstream that has received the incentives?	supply chain ■ Supply chain coordination driven by green technology incentives
8. Following the previous question, what are the incentives you have received and how did you apply for them? P1. Do you think the government financial support has influenced your company's green technology innovation? Why do you think so? P2. Do you think the incentives affect operation decisions and why?	■ The mechanism of incentives to be applied in the supply chain ■ The practical influence of incentives on green technology development ■ Operational decisions affected by the government's incentive policy
9. Has your company participated in the emission trading in Taiwan and for what reasons? P1. If yes, for how long? P2. If yes, has your company traded for buying permit or selling? P3. If no, do you know any if your upstream/downstream take part in the emission trading?	■ Emission trading circumstances ■ Existing mission thresholds ■ The participation of supply chain parties in emission trading

viii. Language of interviews

In this study, Mandarin has been chosen as the interview language due to it being the official language in Taiwan. Despite some of the interviewees speaking a certain degree of English, Mandarin was still selected to avoid any misunderstanding, and also because Mandarin is the interviewees' first language. Before the interview, the English version of the interview guide is translated into Mandarin by a Chinese Mandarin native speaker who well understood the background of this research enquiry. This study also invited a second fluent Mandarin Chinese speaker to translate the Mandarin version of the interview guide into English. All the inconsistencies between these two versions were found and revised.

ix. Interview quality improvement

For the purpose of reducing interviewer bias to improve the interview quality, this study follows the guidance of Brenner, Brown, and Canter (1985):

- Asking the question by reading the written sentences of the interview guide
- Asking the questions slowly and use the correct manner of speaking
- Following the pre-determined order of interview questions to ask the participants
- Ensuring all the interview questions are asked
- Applying the interview response card if necessary
- Using the recording technique through all interviews
- Not to talk about the answers before participants answer the questions

- Expressing an interest in hearing the interviewees' answers
- Ensuring the interviewer fully understands each answer given by the interviewee
- Do not to agree or disagree with the interviewees' answers

In this study, based on the consent of participants, 9 of 11 interviews were recorded by a tape recorder. Another 2 interviews were recorded in written form as requested by the interviewees. During these two interviews, detailed notes were taken to rebuild the interviews afterwards.

x. Data collection summary

11 semi-structured personal interviews were conducted, 10 of them from the car industry and one from a government department. 11 interviews' worth of data was collected over 3 months. At the start of the interviews, participants' names, personal contact details and their company names were recorded. But, on account of the confidentiality agreement in this study, this information has not been revealed in this dissertation, and all the associated companies have also been kept anonymous in the data analysis sections.

5.3 Results

5.3.1 Data analysis

Thematic analysis is chosen to study the qualitative data. This project follows the principles of the thematic analysis indicated by Braun and Clarke (2006). The key concepts and variables derived from the literature were built before the interview, and the interview data emerged later to adjust the model. This study also follows Aronson (1995)'s interview procedure to conduct the thematic analysis as presented in Figure 31. Nvivo 11 software was used to analyse the interview data.

In the thematic analysis, the first step was to collect the data into a transcribable form. The next one was to prepare the transcription for analysis. Initially, the interviews were executed in Mandarin Chinese. Thus, firstly the interview recordings were transcribed into Microsoft documents (Word 2016); Secondly, these transcripts were translated from the Mandarin Chinese version to English before they were analysed. To enhance the reliability of the interview data, this translation was done by a professional translator. Additionally, this study invited a colleague of the researcher, who does not only have a good understanding of the research background but can also speak both English and Mandarin Chinese fluently, to revise these two versions of the transcripts. The inconsistencies have been found were revised.

The third step of the thematic analysis was to identify the categories for coding. In this study, categories were initially identified based on the parameters/components and assumptions of the incentive model. In order to obtain the required information for the incentive model, six categories were pre-determined: government incentives, green technology issues, green car supply chain operations, the market demand trend, and the emission trade. Although these pre-determined categories have covered the majority of the important information needed to establish the model, there may still be unexpected information that might contribute to the enquiry. Thus, new categories were then created accordingly.

The fourth step of the thematic analysis was data coding. Relevant sub-themes were added to the main categories based on the definitions of the categories. There were two parts of coding to ensure its reliability and quality. Firstly, after the first coding, all the interview transcripts were re-coded a few weeks later. All the inconsistency was identified and modified. Secondly, several randomly selected transcripts were coded again by a colleague of the researcher. The coding of these two versions were then compared. In both parts of the coding process, a high level of coding reliability was achieved (above 85 percent) which is considered to be good reliability (Miles & Huberman, 1994).

Next, displaying the data and generating the conclusions. All transcripts were reviewed and coded, and all of the codes were assigned to construct the sub-themes, then the action was repeated several times. After this, the framework of the main themes and sub-themes was summarised to form the arguments and draw the conclusions. The analysis sequence is illustrated in Figure 31.

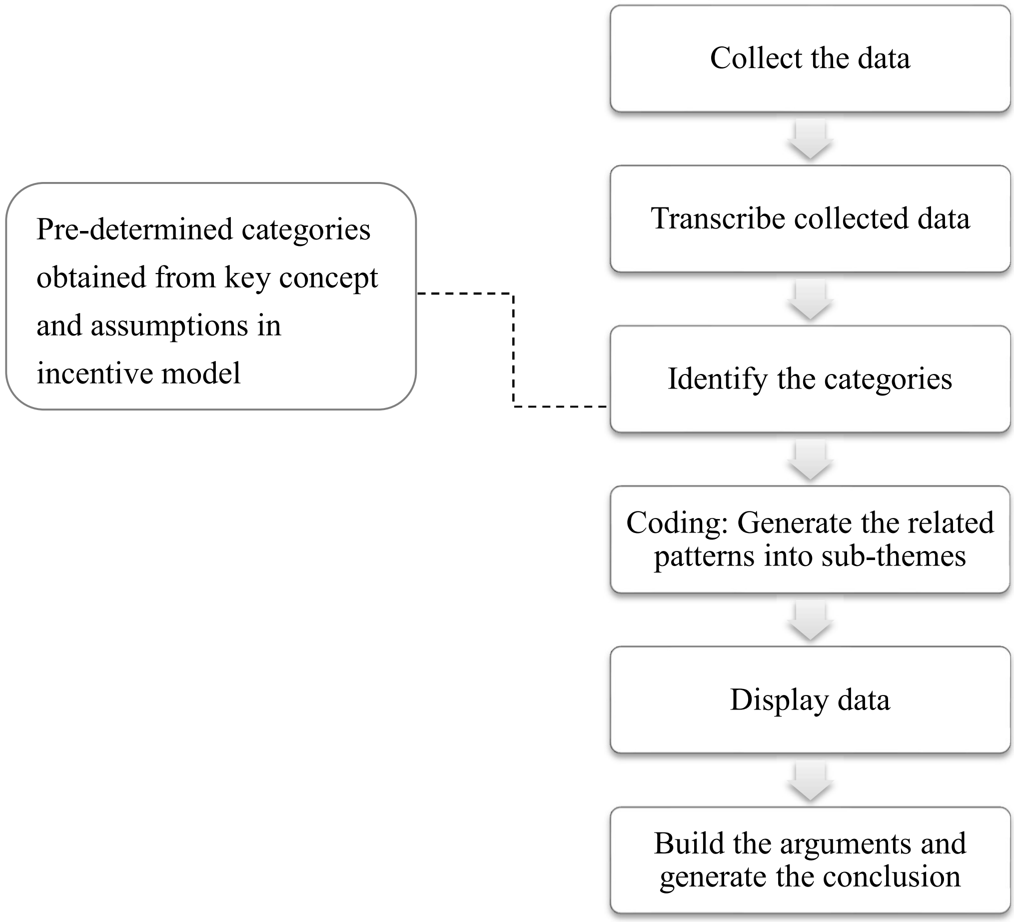


Figure 31 - Thematic analysis process

5.3.2 Development of themes

There are six categories identified in the result of analysis which are Government Incentives, Green Technology, Market Trend and Demand, Green car supply chain, Emission Trade and Other green policies. The following tables present the themes and sub-themes for each category.

Category 1: Government Incentives

Firstly, Under the category of government incentives, it was found that the majority of interviewees indicated government incentive has an effect on supply chain operations. The affected direct supply chain decision including Production related decision (see Quote C1-1 in Table 5), Price (see Quote C1-2 in Table 5) and Product design (see Quote C1-3 in Table 5). At the same time, apart from these supply chain decisions, indirect effect on supply chain operations regarding green car development and investment was also revealed (see Quote C1-4 and C1-5 in Table 5). Although the majority of interviewees have revealed the effect of government incentives on supply chain operations, there was one interviewee indicated government incentives have no influence on supply chain operations due to this company is at the early stage of incentive project (see Quote C1-6 in Table 5).

In addition, government incentives for supply chain and consumers are both revealed. Incentives for supply chain, including the supplier and the manufacturer; Incentives for consumers was also indicated (see Quote C1-7 in Table 5). When the government provides incentive to the car industry in Taiwan, the first step is an application of the incentives made by supply chain parties to the government (see Quote C1-8 in Table 5) such as the *Industrial Technology Development Program (Section industry professionals)*" and *Small Business Innovation Research Program (SBIR)* in Taiwan. During the incentive period, the government monitors the progress and performance of the green technology innovation (see Quote C1-9 and C1-10 in Table 5). Companies are asked to submit a report in each funded period and the government committees review their performance then adjust their incentive rate accordingly (see Quote C1-11 and C1-12 in Table 5). In the incentive project, supply chain parties consider their investment cost and profit when involving in green technology innovation (see Quote C1-13, C1-14 and C1-15 in Table 5). It was also indicated that the decision making in incentive project is based on meeting government expectations (see Quote C1-16 in Table 5).

Category 2: Green Technology

Regarding the determinant parties of green technology, manufacturer and supplier are identified in most of the interviews (see Quote C2-1 in Table 5). Quote from TOYOTA manufacturer: "*TOYOTA and LEXUS we have factories in Taiwan, some of our car models are imported as parts and only assemble in Taiwan but some are manufactured in Taiwan*"; "*Our up-stream, suppliers, have also applied for government funding*", it can be observed that both the supplier and the manufacturer have influence on green technology and they both participate in the government incentive project. Two Taiwanese local car brand, Yulon-Nissan and Luxgen recently have also participated in manufacturing green cars. At the same time, the theme of "Suppliers from other countries" was also identified (see Quote C2-4 in Table 5). In addition to the influence of the manufacturer and the supplier on green technology, one of the interviewees, a government official has indicated the importance of the government in green technology development of green cars (see Quote C2-5 in Table 5).

When supply chain parties discussing the drivers of making green technology investment, a list of reasons are mentioned, including Regulation (see Quote C2-6 and C2-7 in Table 5), Profit (see Quote C2-8 in Table 5), Market trend (see Quote C2-9 in Table 5), High fuel price (see Quote C2-10 in Table 5), Having good relationship with government (see Quote C2-11 in Table 5), For potential future market (see Quote C2-12 in Table 5), Competitive advantage (see Quote C2-13 in Table 5), Being environmentally friendly, CSR reason (see Quote C2-14 in Table 5).

For car supply chain parties, a car's green technology is defined as fuel efficiency (see Quote C2-15, C2-16 and C2-17 in Table 5); Car's greenness (level of environmental friendliness) (see Quote C2-18 in Table 5). Specifically, the green technology of green cars is mainly affected by the green degree of three key components, Motor, Engine, and Battery (see Quote C2-19 in Table 5). The motor was indicated in the interviews (see Quote C2-20 and C2-21 in Table 5). Engine (see Quote C2-22, C2-23 and C2-24 in Table 5) and Battery (see Quote C2-25 in Table 5) are also identified to be influential to car's green technology in the interviews.

To improve the green technology of green cars, there are few obstacles and difficulties revealed by participated supply chain parties. One of the reasons is financial difficulty such as short of funds (see Quote C2-26 and C2-27 in Table 5). Secondly, Technological difficulty in Taiwan is also another reason that car supply chain cannot improve their technology significantly (see Quote C2-28 in Table 5). Thirdly, Green technology expert recruitments problem (see Quote C2-29 in Table 5).

Category 3: Market trend and Demand

In the green car market in Taiwan, there are few issues appeared to be associated with consumer choices. Firstly, price is indicated as one of the factors (see Quote C3-1 and C3-2 in Table 5). In addition to price, green technology is also mentioned as a key factor which relates to consumer purchasing behaviour (see Quote C3-3 in Table 5). Other factors that have an influence on green car purchasing behaviour are Green preferences (see Quote C3-4 in Table 5), Warranty (see Quote C3-5 in Table 5), Fuel price (see Quote C3-6 in Table 5) and Charging station (see Quote C3-7 in Table 5).

Category 4: Green car supply chain

In the green car supply chain, the manufacturer must source the part from the supplier because of the complexity of car parts. However, it was found that vertical integration takes place in the car supply chain when specific components contain key technologies (see Quote C4-1 and C4-2 in Table 5).

In the car supply chain, supplier and manufacturer are our targeted interviewees. Expect these two parties, there are few more tiers have been indicated in the interview "Retailer" and "Dealer" from direct and non-direct selling store, and "Aftermarket". Cooperation between the supplier and the manufacturer is mentioned (see Quote C4-3 in Table 5). The supplier and the manufacturer's decision-making are the main focuses of this study. For supplier's operational decisions in incentive projects, several keywords have been indicated, including Price (see Quote C4-4 in Table), Motor (see Quote C4-5 in Table 5), Engine (see Quote C4-6 in Table 5), Battery (see Quote C4-7 in Table 5) and airbag (see Quote C4-8 in Table 5). For the manufacturer's operational decisions, "Price" and "Car design" have been indicated in the majority of the interviews. Price refers to the price of the green cars offered to the market (see Quote C4-9 in Table 5). Several key words regarding manufacturer's car design decisions including "*Weight*"; "*Transmission*"; "*Tyres*"; "*Software system*"; "*R&D*"; "*Motor*"; "*Key component*"; "*Engine*"; "*Car Interior*"; "*Car body*"; "*Battery*".

Both the supplier and the manufacturer indicated their objectives are maximising the profit (see Quote C4-10 and C4-11 in Table 5). A manufacturer said: "*When manufacturing a green car, we only consider whether it can be sold to the market and whether it is profitable*", and a supplier said "*Our equipment cost and variable cost will be summed up, as long as there is a reasonable profit we will continue to supply parts to the manufacturer*". As profit reflects the difference between the cost and revenue, "*Cost*" was mentioned as another keyword in the supplier and the manufacturer's objectives.

Category 5: Emission Trading

No evidence in the collected data shows car supply chain parties have participated in emission trading, but one manufacturer indicated will consider in the future (see Quote C5-1 in Table 5). One of the interviewees, government officer has indicated that the car industry hasn't participated yet (see Quote C5-2 in Table 5). Only one company has indicated its intention to consider emission trading (see Quote C5-3 in Table 5). For this company which is on developing stage, it was indicated that this plan of participation in emission trading aims to follow government policy (see Quote C5-4 in Table 5). However, the majority of the interviewees expressed no experience in emission trading. When they are asked their intentions of participation emission trading in the future, themes of "*Unnecessary to participate*" (see Quote C5-5 in Table 5), "*Other or no specific reasons*" and "*No current exact regulation for the emission of production*" were identified. Thus, currently, supply chain parties don't have the pressure of managing emissions. In Taiwan, emissions regulations only applied in few specific industries, car supply chain parties who have the intention to participate mainly due to "*Reduce emissions in production for future green policy*" and "*Cooperation with government's future emission trade relevant policy*".

Category 6: Other green policies

Expect the incentive related green policy, there are several other green policies have been mentioned in the interview. Supply chain parties believe the government will introduce new emission regulation and increase the number of charging stations in Taiwan. It was also indicated by a manufacturer that the Chinese government pays more attention to promote green car innovation in the supply chain compared to the Taiwanese government. Besides, there is clear emission regulation for car supply chain in China. Another green polices in Taiwan indicated were Green Mark, Green incentives for scooters and Free parking incentives for green cars.

Table 5 - Quotes from the semi-structured interviews

Quote number	Quote from the interviews
Quote C1-1	*We have added two production lines with an extra team to manage government project*
Quote C1-2	*We can provide green cars to the market with a more affordable price*
Quote C1-3	*The material used for the body of the car is more high-temperature resistance in our green cars, without government incentives we will not use this because the cost is higher than normal materials*
Quote C1-4	*We started to invest in green cars production since we received the government's funding*
Quote C1-5	*Our green technology innovation department was set up to cope with government incentive project*
Quote C1-6	*The current technology innovation plan is based on the company's marketing strategy and it is not entirely dependent on government incentives*
Quote C1-7	*Government has been offering tax reduction for green cars consumers in the past few years*
Quote C1-8	*The government decided an initial incentive rate to our proposed plan*
Quote C1-9	*Government officers came to check if we have achieved what we have proposed in the proposal of the funding*
Quote C1-10	*The government looked at our green technology at the end of each term and compared it with the previous period. The review is basically dependent on whether we have better or worse green technology in the current term*
Quote C1-11	*Last year, the government reduced the percentage of the incentive in the budget of the technology project after the substandard periodical review*
Quote C1-12	*Our incentive rate is cut down from 14% to 8% because last term's review result was not very satisfactory*
Quote C1-13	*We only invest in green cars development when it is profitable*
Quote C1-14	*Our manager wants to apply for government incentive funding to cover some of our cost of green technology innovation because it is very likely to have a negative profit in the first few years of the green technology investment*
Quote C1-15	*We won't be able to improve the technology of manufacturing without national science department's funding*
Quote C1-16	*Our company normally follow government project's plan closely in order to continually receive the funding from the government*
Quote C2-1	*A green car's core green technology and its market value are dependent on the original car design team, including mid-stream in the supply chain which is the supplier, and down-stream supply chain party which is the manufacturer*

Quote C2-2	*TOYOTA and LEXUS we have factories in Taiwan, some of our car models are imported as parts and only assemble in Taiwan but some are manufactured in Taiwan*
Quote C2-3	*Our up-stream, suppliers, have also applied for government funding*
Quote C2-4	*There are many parts in one car, we buy them from different countries such as China, Europe and America*
Quote C2-5	*Five government departments are involved in promoting green car's technology innovation, including Bureau of Energy (Ministry of Economic Affairs), Environmental Protection Administration (Executive Yuan), Ministry of the Interior, Ministry of Finance, and Department of Industrial (Technology Ministry of Economic Affairs*
Quote C2-6	*Government's regulation has become more and more strict, this is why we are actively developing green cars*
Quote C2-7	*National-Sixth regulation (car's emissions regulation) is very strict now and manufacturing green cars is the only way to lower the emissions*
Quote C2-8	*When manufacturing a green car, we only consider whether it can be sold to the market and whether it is profitable*
Quote C2-9	*Green car is a future market trend*
Quote C2-10	*Fuel price increases so consumers buy more green cars than before*
Quote C2-11	*This incentive project is not only for receiving funding in these three years but also maintain a good relationship with the government department*
Quote C2-12	*Now we don't expect to have profit from these green car models because the innovation cost is very high at the beginning, however, we target China market as the potential market which has a significantly bigger scale than Taiwan*
Quote C2-13	*When other brands are all producing green cars, we need to participate to maintain a competitive advantage*
Quote C2-14	*Especially our CSR department who is active to make the company's image to link to environmentally friendly by promoting green car models*
Quote C2-15	*The most important factor to measure the car's green technology is its MPG (miles per gallon)*
Quote C2-16	*Greener cars consume less fuel when driving*
Quote C2-17	*Green technology means the level of saving the fuel consumption*
Quote C2-18	*Green technology is related to car greenness*"; "*I think a green car is an environmentally friendly car*
Quote C2-19	*A green car's battery, engine and motor are the most important key components regarding its fuel efficiency*
Quote C2-20	*For green car models, we need a good motor so we adopted the motor from Tomita Motor who has also supply TESLA*
Quote C2-21	*The supplier will make the motor based on international standard and the requirement we*

	proposed
Quote C2-22	*We manufacture engine by ourselves because we cannot find a suitable engine from other suppliers, the engine is one of our key technology so we don't want to use other brand's engine*
Quote C2-23	*The engine is the most expensive component in the green car and the design of the engine is related to fuel efficiency*
Quote C2-24	*It's very expensive to design a new engine so MAZADA and Nissan have used the same R18 engine in some of their car models, HONDA always let the supplier develop new engines, so their car price is more expensive than TOYOTA*
Quote C2-25	*Part of the fuel consumptions is replaced by the battery in green car design, the battery can supply the electricity to drive the motor, the green technology of battery is very important, so we have to intervene*
Quote C2-26	*Now we don't expect to have profit from these green car models because the innovation cost is very high at the beginning*
Quote C2-27	*We won't be able to improve the technology of manufacturing without national science department's funding*
Quote C2-28	*The scale of Taiwanese green car market is small, and scale of car companies are relatively small as well, unlike other international car companies can have the latest green technology innovation*
Quote C2-29	*It is very difficult and expensive to hire suitable professional experts in Taiwan*
Quote C3-1	*Consumer only buy the cars they can afford, that is why in Taiwan you can see those cars prices lees than 100 million TWD is more popular than expensive ones*
Quote C3-2	*Car consumers are very sensitive to the price*
Quote C3-3	*Except for the green technology from our innovation department, supplier's technology and price of the parts are important and they also affect the final price offered to the market. Our goal is to sell the car, the more the better, if the price is too high then it will be difficult to sell*
Quote C3-4	*Some consumers naturally prefer green products so they buy green cars, we also found some consumers only care about how much they can save in the future with a green car*
Quote C3-5	*Battery problem is another issue, normally you need to change the green car's battery every five years. I don't know why suppliers haven't overcome this problem. In fact, it is an extra cost for consumers, so some car seller provides a warranty to cover a few years*
Quote C3-6	*People buy green cars to save the expense of fuel, especially when the fuel prices increases in some years, green cars become more popular*
Quote C3-7	*In the city areas, the charging services is limited. There are nearly no charging stations in the mountain areas so electric cars are still not accepted widely by consumer now*
Quote C4-1	*We manufacture batteries for I3 and I8 series, another example, LEXUS also produce their batteries for green cars. We need to make sure we own the special technology, although it is*

	cheaper to buy from a supplier, as long as we can sell cars to market, we will still produce batteries by ourselves
Quote C4-2	*We used to buy the engine from Huaching, but now we have merger Huaching into our company*
Quote C4-3	*We need to manage our "know-how" by ourselves but also discuss with our supplier, asking the supplier to produce a part with a good level of quality to meet our requirement. For green technology development and car design, I think we cannot be totally independent*
Quote C4-4	*We open the mould to produce the part, providing to different channels, normally we decide the price of the part sold to the manufacturer, but the price cannot be too high*
Quote C4-5	*We design a motor to fulfil manufacturer's needs, motor relates to a car's driving duration*
Quote C4-6	*The manufacturer comes to us for a specific engine but normally they have known what kind of engine they need. There are four levels of certification for engine suppliers, the manufacturer will seek for the one with right level as their engine supplier*
Quote C4-7	*We produce batteries for hybrid and electric cars, the batteries for electric cars can determine its duration. The design of the battery is much more complicated than a car's motor*
Quote C4-8	*For example, TOYOTA and Honda have been using the same airbag. The technology level of an airbag is not as important as engine or battery because no company wants to invest in developing the airbag*
Quote C4-9	*The market price is normally set by the car manufacturer, car dealer or the store sales cannot change it*
Quote C4-10	*When manufacturing a green car, we only consider whether it can be sold to the market and whether it is profitable*
Quote C4-11	*Our equipment cost and variable cost will be summed up, as long as there is a reasonable profit we will continue to supply parts to the manufacturer*
Quote C5-1	*Our company doesn't join emission trading, maybe head office will consider this in the future*
Quote C5-2	*At the moment, emission trading in Taiwan only high-tech industry has involved, car supply chain hasn't participated*
Quote C5-3	*I was told that we are still evaluating the possibility of joining emission trading soon, so we don't buy or sell any in emission trading now*
Quote C5-4	*We know the government is going to have emission regulation soon so emission trading will become a trend in the industry*
Quote C5-5	*I don't think emission trading is necessary for Taiwan, we don't have that market. One of our suppliers in Germany has joined emission trading, that's because they have the market*

Table 6 - Identified theme - Category 1: Government Incentives

Category	**Sub-themes**			
Government Incentives	1. Influence of incentives on supply chain operations	1. Government has no effect		
		2. Government has an effect	i. Supply chain decisions	a. Production related; b. Price; c. Product design
			ii. Green car development and investment	
	2. Incentives for the supply chain			
	3. Incentives for the consumers			
	4. Government green incentive projects in the supply chain	1. Incentives application		
		2. Project processing	I. Regular review by government	a. Report for government
				b. The evaluation performance regarding green technology improvement
			II. Technology investment and renew the production lines	a. Profit consideration
				b. Cost consideration
				c. Meet the government's expectation/requirement

Table 7 - Identified theme - Category 2: Green Technology

Category	**Sub-themes**			
Green Technology	1. Determinant parties	1. Manufacturer	1. Manufacturers in Taiwan	a. TOYOTA; b. LEXUS; c. Yulon-Nissan; d. Luxgen; e. Volvo; f. BMW; g. HONDA
			2. Manufacturers in other countries from the upper stream of the supply chain	a. TOYOTA; b. Volvo; c. BMW
		2. Supplier	1. Suppliers in Taiwan	a. TOYOTA; b. LEXUS; c. Yulon-Nissan; d. Luxgen
			2. Suppliers from other countries	a. China; b. U.S.; c. European countries
		3. Government	1. Bureau of Energy, Ministry of Economic Affairs	
			2. Environmental Protection Administration, Executive Yuan	
			3. Ministry of the Interior	
			4. Ministry of Finance	
			5. Department of Industrial, Technology Ministry of Economic Affairs	

	2. The drivers of making green technology investment	1. Regulation	
		2. Profit	
		3. Market trend	
		4. High fuel price	
		5. Having s good relationship with government	
		6. For potential future market	
		7. Competitive advantage	
		8. Being environmentally friendly, CSR reason	
	3. Key components of green technology	1. Motor	
		2. Engine	
		3. Battery	
	4. Definition of green technology	1. Fuel efficiency	
		2. Car's greenness (level of environmental friendliness)	
	5. Barriers to green technology improvement	1. Short of funds	
		2. Technological difficulty in Taiwan	
		3. Green technology expert recruitments problem	

Table 8 - Identified theme - Category 3: Market trend and Demand

<table>
<tr><th>Category</th><th colspan="2">Sub-themes</th></tr>
<tr><td rowspan="8">Market Trend and Demand</td><td>1. Price</td><td rowspan="2"></td></tr>
<tr><td>2. Charging station</td></tr>
<tr><td rowspan="3">3. Green technology</td><td>1. MPG (fuel efficiency)</td></tr>
<tr><td>2. level of Environmentally friendliness</td></tr>
<tr><td>3. Car performance and endurance</td></tr>
<tr><td>1. Warranty</td><td rowspan="3"></td></tr>
<tr><td>2. Fuel price</td></tr>
<tr><td>3. Green preference</td></tr>
</table>

Table 9 - Identified theme - Category 4: Green car supply chain

<table>
<tr><th>Category</th><th colspan="4">Sub-themes</th></tr>
<tr><td rowspan="17">Green car supply chain</td><td>1. Vertical integration</td><td colspan="3"></td></tr>
<tr><td rowspan="7">2. Supplier</td><td rowspan="5">1.Operation decisions</td><td>1. Price</td><td rowspan="7"></td></tr>
<tr><td>2. Motor</td></tr>
<tr><td>3. Engine</td></tr>
<tr><td>4. Battery</td></tr>
<tr><td>5. Airbag</td></tr>
<tr><td rowspan="2">2. Objective</td><td>1. Profit</td></tr>
<tr><td>2. Cost</td></tr>
<tr><td rowspan="4">3. Manufacturer</td><td rowspan="2">1.Operation decisions</td><td>1. Price</td><td></td></tr>
<tr><td>2. Car design</td><td>a. Weight; b. Transmission; c. Tyres; d. Software system; e. R&D; f. Motor; g. Key component; h. Engine; i. Car Interior; j. Car body; k. Battery</td></tr>
<tr><td rowspan="2">2. Objective</td><td colspan="2">1. Profit</td></tr>
<tr><td colspan="2">2. Cost</td></tr>
<tr><td rowspan="2">4. Dealer, Retailer</td><td>1. Direct selling stores</td><td colspan="2" rowspan="4"></td></tr>
<tr><td>2. Non-direct selling stores</td></tr>
<tr><td>5. Cooperation/coordination in the supply chain</td><td rowspan="2"></td></tr>
<tr><td>6. Aftermarket</td></tr>
</table>

Table 10 - Identified theme - Category 5: Emission Trading

Category	Sub-themes		
Emission Trading	1. Participating	1. The manufacturer does not join	
		2. Decision made by the company head office	
	2. On developing stage	1. Planning for future government policy	
		2. Planning to join the emission trading soon	
	3. No experience	1. Reason for not participating	1.Unnecessary to participate 2. Other or no specific reasons 3. No current exact regulation for the emission of production
		2. Will consider emission trading for future plan	1. Reduce emissions in production for future green policy 2. Cooperation with the government's future emission trade relevant policy

Table 11 - Identified theme - Category 6: Other green policies

Category	Sub-themes	
Other green policies	1. Future government policy	1. New emission regulation
		2. Charging station
	2. Green policy in China	1. Emissions regulation
		2. Balance of grey and green car manufacturer
	3. Green mark	
	4. Green incentives for scooters	
	5. Car emission regulation	
	6. Free parking incentives	

5.3.3 The use of collected data in the incentive model in Main Study 3

- Application of qualitative data 1:

  i. Corresponding component in the model: Demand function, car greenness definition, background case

  ii. Corresponding model assumptions:

  - The demand of green vehicle is price and green technology dependent.
  - Higher greenness of the vehicle has less fuel consumption during driving (better fuel efficiency).

Implications from interview	Adjustment in the model
• Background cases: Nissan, Lexus, TOYOTA, BMW, Luxgen. • Factors of consumer preferences indicated are price and green technology (MPG, operation performance and endurance), charging stations, warranty, fuel price, green preference. • The government uses the Green Mark Standard to evaluate the green technology level of businesses including the car industry.	• Use the revealed example to establish the background case for the whole model (actual case from the car industry in Taiwan). • Car greenness (green degree of the car) is based on the combination of the supplier and manufacturer's green technology improvement. • The demand function is built based on vehicle price and car greenness which is presented in section 6.2.4 in Main Study 3. • Secondary data to be adopted in greenness variable: MPG (miles per gallon is used to

	indicate greenness of the vehicle.

Summary of application 1:

Application of qualitative data 1 includes the background cases to the incentive model, decision makers of car greenness and the key factors affecting market demand. In addition, the collected data, car sales data in Taiwan (2011 to 2015) has been used to obtain the distributions of the sensitivities of price and green technology for use in Main Study 3.

- Application of qualitative data 2:
  - i. Corresponding component in the model: Identifying decision makers, the definition of car greenness
  - ii. Corresponding model assumptions:
    - Both the supplier and manufacturer's green technology level will affect the car's final greenness.
    - The supplier and manufacturer have pricing and technology decisions to make in the product innovation process.

Implications from interview	Adjustment in the model
• Supplier and manufacturer are the two main parties who determine the vehicle's greenness (depends on their green technologies), and receive incentives from the government. (decision makers).	• Supply chain parties: both supplier and manufacturer will be included in the incentive model who have interactions with the government and the consumer. • Car greenness is determined by both the supplier and

• Decision variable: Price (reflected by cost), green technology decision: manufacturer decides motor, engine and battery to use, designing vehicle integration system; supplier produces these key parts to support/sell to the manufacturer. • Government incentives are important for green technology development: the better the performance of green technology improvement, the higher the incentive percentage. Quote from the interview, "*We won't be able to improve the technology of manufacturing without national science department's funding*."; *"Our incentive rate is cut down from 14% to 8% because last term's review result was not very satisfactory"*. • In the green car market, the greener the car and the lower price, the better the sales. Consumers consider not only the price but also the car performance when selecting cars. Consumers care about the car's fuel efficiency the most,	manufacturer's green technology, it is assumed that there is a proportion of the supplier's green technology level that contributes to car greenness, and there is a proportion of the manufacturer's green technology's effect on the final car greenness, and the total of these two factors equals one. The above demonstrates that the final car greenness is reflected by both the supplier and the manufacturer's green technology levels. This argument has been applied in section 6.2.2 in Main Study 3. • The supplier and manufacturer decide their pricing and technology decisions every period under the principle of profit optimisation. • Definition of green technology improvement is the parentage of *improvement* between the original green technology level and the level after the investment of green technology. When supply chain parties have no green technology investment, there is no technology improvement. From application 1, it is assumed that the product

other indicators matter variously between individuals. • No capacity limitation problems have been indicated by neither the supplier nor the manufacturer.	greenness can boost market demand to a certain degree, thus a positive effect from product greenness on demand is formulated in section 6.2.4 in Main Study 3. • Assumption of unlimited production capacity is supported.

Summary of application 2:

Application of qualitative data 2 has identified the associate parties in the car supply chain who have participated in the government's green inventive project and their relevant decision making. Car greenness and market demand function are also built based on the information revealed and these findings are applied in Main Study 3.

- Application of qualitative data 3:
  - i. Corresponding component in the model: Supply chain objectives
  - ii. Corresponding model assumptions:
    - ➢ The supplier and the manufacturer have their own objective and their decision making depends on profit maximisation.
    - ➢ Supply chain parties cooperate with the government regarding green technology development.

Implications from interview	Adjustment in the model
• Main motivation and objective for the supply chain is profit, profit extend reason: market	• The objective function for supplier and manufacturer is profit maximisation in the model,

potential and current trend, Chinese market, competitive advantage. • Green technology costs include variable cost and fixed cost. • Other factors also revealed such as "good for company" reason: Corporate image, relationship with the government. • In the green incentive projects, the government covers a certain percentage of the cost of green technology investment in the proposed project as incentives provided to the supply chain.	objective functions are presented in section 6.2.5 in Main Study 3. • In the objective function, supply chain parties' manufacturing cost is based on a fixed and a variable cost. Incentives from the government are not given per product unit sold as assumed before but are funding based. A certain percentage of the project's investment is covered by the incentives and given periodically. • The incentive is formulated as a percentage of production cost, including fixed cost and variable cost. This is used as an incentive given method in the supply chain in Main Study 3, called "government incentive rate".

Summary of application 3:

Firstly, the application of qualitative data 3 presents supply chain parties' motivation in participating in the government's green technology incentive project and their objectives of decision making. Secondly, the cost function is formulated into two parts, variable cost and fixed cost. Thirdly, the government's incentive giving method is identified for use in Main Study 3.

- Application of qualitative data 4:
  i. Corresponding component in the model: Government incentive mechanism, green technology improvement review, and incentive rate adjustment

ii. Corresponding model assumptions:

- ➢ The government provides incentives to supply chain in order to promote green technology development.
- ➢ The incentive is provided per unit, separately to the supplier and the manufacturer.
- ➢ Government reviews companies' technology performance and changes the incentive rate depending on the green technology level.

Implications from interview	Adjustment in the model
• Consumers have the fuel taxes and vehicle license tax reduction for hybrid and electric vehicles, the reduction is a fixed amount and applied per car. • The incentives provided in the car industry in Taiwan include: (1) Excise from 30% reduces to 15% for hybrid cars; reduces to 0% for electric cars. (2) R&D green technology funding, national innovation and investment support funding: By proposing a research project to apply for funding, an incentive rate is assigned after the approval of project application. • In some cases, the manufacturer and supplier apply for the funding together and share the review, but the incentive percentages are independent.	• Tax reduction is not considered in this study because it is the consumer's buying benefit instead of the supply chain's green technology investment's benefit which is not the focus of the study. Tax shows no difference in different car models. • Government incentives include "excise reduction", "technology funding", only green technology funding project is adopted because "excise reduction" remains consistent between different car greenness levels of car models. • An initial incentive rate is given for the first period of the project. • Incentive rate changes depending on the previous period's project review, this is applied to establish section 6.2.3 in Main Study 3. • Project reviews are based on the

• The government expects supply chain parties to progress gradually the green incentive project, companies are asked to demonstrate the improvement in green technology in each review period. • The government adjusts the incentive rate after the periodical review. The rate increases when the performance is better than the expected improvement and decreases when the company fails to achieve the planned progress.	change of green technologies improvement between last and current period, it is also affected by the government's technology change sensitivity on incentive rates. This application is presented in section 6.2.3 in Main Study 3.

Summary of application 4:

Application of qualitative data 4 includes the selection of government incentive policy adopted in this project, details of government incentive mechanism, supply chain parties' green technology improvement review, and government's incentive rate adjustment mechanism. The relevant components and functions in the model of Main Study 3 are built and revised accordingly.

- Application of qualitative data 5:
  i. Corresponding component in the model: Emission trade mechanism in car supply chain
  ii. Corresponding model assumptions:
    - Supply chain parties in the car industry have participated in the

emission trade market.

Implications from interview	Adjustment in the model
• Government has been promoting it but no car company has actually participated in Taiwan but for the hi-technology industry. • Only Kuozui (TOYOTA manufacturer) has considered emission trade and it is still under development.	• Although emission trade does not yet prevail in the car industry, still emission trade is part of the incentive model in terms of the Taiwanese government's aims to apply it comprehensively in industries in 2020, and the car industry is one of the targets. • The decision making of emission trade in the supply chain is deleted from the model in Main Study 3.

Summary of application 5:

Based on the literature, it was assumed that emission trade has an influence on supply decision making, however, there is no evidence that the car supply chain has participated in the emission trade market in Taiwan. The emission trade platform has been established in Taiwan in 2010. Until 2012, there were already more than 250 companies in the trade market. The high technology industry was the first group to participate in the emission trade market, but the car industry has not yet done so. Thus, this part of decision making is not included in Main Study 3 and it is considered in further research.

5.4 Conclusion

The components of the game theory model in Preliminary Study 1 have been verified and enhanced by the qualitative empirical research in Preliminary Study 2. The qualitative data in Preliminary Study 2 has shown the details regarding the mechanism of the current government incentive policy and green technology development in the car supply chain in Taiwan. After the data analysis, six pre-determined categories (Green technology issues, Green car supply chain operations, the trend of market demand, and Emission trade) have been modified and updated. Six new categories were identified, including Government incentives, Green technology, Market trend and demand, Supply chain in the car industry, Emission trade, and Other green polices. Several important adjustments have been made. Firstly, the application and allocation in the supply chain of government incentives have been adopted to support the assumptions of the mathematical incentive model. Secondly, supply chain decision making has been used in the formulations of the supplier and manufacturer's behaviour. Thirdly, for the consumer response, market demand is also revised taking into consideration the uncertainties indicated in the interviews. Fourthly, the incentive project performance evaluation and incentive rate adjustment rule have been formulated on the basis of qualitative data. Finally, the emission trade part is deleted from the incentive model as the interview data reveals no evidence that emission trade is applied in the car industry in Taiwan. In summary, most concepts and assumptions of the incentive model have been verified and adjusted or revised based on the qualitative data in Preliminary Study 2 and will be used as the foundation of the simulation model in Main Study 3.

Chapter 6: Main Study 3: Simulation modelling research

6.1 Introduction

6.1.1 Problem description

Governments are seeking to reduce greenhouse gas (hereafter GHG) emissions (Cohen et al., 2015), for example from vehicles, as environmental awareness rises. An incentive policy is recognized by many scholars as an effective approach to control GHG emissions (Chappin et al., 2009; Coria, 2009; Dowson et al., 2012). In the car industry, government incentives have been proved to have a significant impact on the growth of green technology adoption in hybrid vehicles (Diamond, 2009), and emission reduction in general (Cohen et al., 2015). Thus, in order to effectively reduce carbon emissions, it is important for the government to drive green technology adoption in the car industry by effectively allocating incentives (Goulder & Mathai, 2000).

Government incentives are considered to be an investment to achieve a better environment, and to increase welfare. The welfare resulting from incentives is seen as a return on the government's investment in them. Providing such incentives can not only drive the supply chain's green technology innovation in the car industry, but also bring benefits to consumers, and this too is considered as a return on the incentives. To achieve good green policy making, a government must allocate resources reasonably to maximise the efficiency of its incentives. Hence, this research investigates supply chain decision making under green technology incentives provided by the government, to provide insights into government incentive policy management.

6.1.2 Objective of government

For the government's objective, Fischer et al. (2003) suggested that welfare resulting from incentives includes two dimensions: technology innovation for the supply chain and environmental benefits. The first dimension is green technology innovation, that is, the increased ability of the supply chain to manufacture greener products when the government provides incentives. The second dimension is environmental benefits– government incentives can also reduce the environmental impact of product use because emissions are expected to reduce when green technology innovations have been implemented. It is thought that when a higher level of green technology is used in a green product – such as improving the fuel efficiency of a green car, in the present case – consumers also benefit simultaneously because a greener/better product is provided in the market. The environment, supply chain parties, and consumers are all affected by the incentives, and so these three subjects are considered by the government when drawing up an incentive policy.

Krass et al. (2013) proposed a mathematical model to investigate green policies and the choice of green technology; they adopted social welfare maximisation as the government's objective function which is also used by several related studies (Baldwin & Krugman, 2004; Boskin & Sheshinski, 1978; Fischer et al., 2003; Krass et al., 2013). Social welfare is the sum of a firm's profit and consumer surplus, minus its environmental impact (Krass et al., 2013). Based on the above, this research study applied a combination of Krass et al.'s regulatory social welfare objective function and Fischer et al.'s incentive welfare function as the foundation for the government's objective. This objective consists of three parts: consumer benefits from the incentives on the supply chain, supply chain-based producer surplus (profit) and the environmental impact from product use. It is assumed in this study that the government's objective is to maximise the welfare resulting from its incentives (Boskin & Sheshinski, 1978) while maintaining a balance between environmental impact, supply chain profit, and consumers' benefits. The three parts of the government objective are presented in section 6.2.6.

6.1.3 Government incentives

There are two categories of financial incentives for green technology development provided by the Taiwanese government. The first category is funding-like incentives, such as the Innovation Technology Application and Service (ITAS) project originating from the Ministry of Economic Affairs (Taiwan Ministry of Economic Affairs, 2016), and the Industry Technology Development Program (ITDP) (Taiwan Ministry of Economic Affairs, 2004), which has been applied to car supply chain in Taiwan. Both of them aim to alleviate technology investment costs to a certain extent, although ITDP is applicable for most industries while ITAS is only applicable to some specific industries. Funding-like incentives are applicable to both suppliers and manufacturers in the car supply chain in Taiwan.

The second category of financial green incentive is excise, which attempts to lower costs for manufacturers. An example of excise in Taiwan is a 30% discount on cargo tax for electric vehicles in general. However, there is no excise difference among different car models. That is to say, although tax reduction can lower the sale prices of all electric hybrid cars, it does not result in any difference in price discounts for different car models. Thus, tax reduction is not regarded as a decisive factor in the incentive model to improve green technology in the car industry. Therefore, only funding-like technology incentives are considered in this project.

6.1.4 Government's green technology innovation incentives

This research study focuses on the main green technology incentive policies in the car industry. In Taiwan's car industry, suppliers and manufacturers can apply for government funding to financially assist their green technology innovation. The proposed budget of an innovation project is evaluated, and then a certain percentage of the budget is funded by the government as a green technology incentive. Having been funded by the government, the performance of the project is reviewed by the relevant government department at the end of a period, and an incentive rate adjustment is made accordingly for the next period's incentive rate. The incentive rate in the present period is thus dependent on the evaluation result and the incentive rate of the previous period. That is, supply chain parties receive various incentive rates depending on the performance of their green technology. In order to maintain an incentive rate, supply chain parties need to ensure their green technology level aligns with the expected outcome proposed in the first place.

A technology innovation incentives example from HAITEC

HAITEC is a leading hybrid car manufacturer in Taiwan. HAITEC applied for funding for a green technology innovation project with a development plan. Quotation from the interview with HAITEC: "The g*overnment has approved the proposal of the incentive project and then gave us an incentive equivalent to 14% of the proposed budget for this project. The government's representatives (academics from the relevant fields) then came to the factory and reviewed the green technology performance at the end of a certain month. We also had a meeting with them. After that, the second term's incentive rate was decreased because the review result was not good.*" In their case, the incentive rate dropped from an initial 14% in the first period to 8% in the second period, because the green technology level fell. However, in period 3, the incentive rate was increased back to 14%, as the green technology level had increased significantly during period 2.

6.2 Method

6.2.1 Notation

T_s : The green technology level of the supplier

T_m : The green technology level of the manufacturer

w : The per-unit wholesale price charged to the manufacturer by the supplier

p : The price of the product in the market

G_s : The incentive rate given by the government to the supplier

G_m : The incentive rate given by the government to the manufacturer

Q : Market Demand

a : Market size

b : The sensitivity of the market price's influence on the demand function

c : The factor/sensitivity of the product's greenness in the demand function

α : The influence of the supplier's green technology level on the product's final greenness, illustrated by a weight

β : The influence of the manufacturer's green technology level on the product's final greenness, illustrated by a weight

C_f : The marginal fixed cost of improving green technology for the supplier

C_d : The marginal fixed cost of improving green technology for the manufacturer

C_s : The variable production cost for the supplier

C_m: The variable manufacturing cost for the manufacturer

R_s : Government green technology review for the supplier

R_m : Government green technology review for the manufacturer

ε_s : The influence of the government's green technology review on incentive adjustment for the supplier, illustrated by a factor

ε_m : The influence of the government's green technology review results on incentive adjustment for the manufacturer, illustrated by a factor

π_s : Profit of supplier

π_m : Profit of manufacturer

E_m : Total emissions

6.2.2 Green technology

I Green technology definition

Green technology, or environmentally friendly technology, is technology applied to a product which results in less of an environmental impact from that product's use. Green technology is recognized as clean technology (Hall & Helmers, 2013) and emissions-reducing technology (Krass et al., 2013). Green automobile technology is low-emission technology, which is the technology innovation for green cars (Daziano & Bolduc, 2013). These definitions point out that green technology can help with reducing emissions because it can reduce energy consumption. In addition, from the interview data in Preliminary Study 2, two themes have been identified to define green technology: one is a car's level of *environmental friendliness,* and the other is its *fuel efficiency*. Thus, by taking account both of the literature and evidence from qualitative data, this study contends that green technology is indicated by greater fuel efficiency, a higher green technology level, and lower driving emissions.

II Decision makers of green technology in the car supply chain

In the car supply chain, suppliers and manufacturers have their own green technology levels. For suppliers, the green technology level is reflected in the selection of materials and relevant green inputs during the components' manufacturing process. For instance, Interviewee no. 4 stated that "*Suppliers frequently chose the high temperature-proof material, which is more expensive, yet more environmentally friendly, in order to increase the efficiency of fuel use as well as the green technology level"*. For the manufacturer, the green technology level relates to the design of car systems and the manufacturing of key components. It is also confirmed in the interview that the only two key roles deciding a car's greenness are the supplier and the manufacturer (details can be found in the *application of qualitative data 2* in Preliminary Study 2). This coincides with the literature, suggesting that both suppliers and manufacturers have an impact on the greenness of a product (Lee & Kim, 2011). Therefore, in this study, the supplier and the manufacturer each has a green technology decision to make, and their combined green technology levels determine the car's greenness.

III Green technology level in the car industry

From a practical point of view, the green technology adoption of a car depends on two aspects. Firstly, the manufacturing of key components for hybrid electric vehicles, such as the selection of the engine and the battery (Fish & Savoie, 2001). A quotation from an interview illustrates this point: "The *focus of green technology for hybrid cars involves the engine, battery and motor for electric hybrid vehicles; the battery and engine for electric vehicles*". These key components are partially designed and produced by the suppliers, and then assembled into ready car parts for the manufacturer to use in production. Secondly, the system design for green cars is different from traditional cars in terms of the charging system, pumped storage system, and the drive system (Green & Kellawa, 1997). The required components are designed and manufactured by the supplier and are integrated into the relevant car systems (charging system, pumped storage system, drive system, etc.) by the manufacturer. To conclude, the two categories above, regarding the supply chain green technology level, are designed mainly by the manufacturer and the components are supplied by the supplier.

For the supplier and manufacturer, the green technology level is the green degree of these key components and the car systems. That is, their green technologies are based on manufacturing key components and on designing the car systems which then determine the car's emission levels. According to this, this study uses car emission levels to measure car greenness, and car greenness has relied on both the supplier and manufacturer's green technology levels.

IV Green technology decision variables

In each period, the supplier and the manufacturer have their own level of green technology level and they are presented by the following parameters, T_{s_t} and T_{m_t} are supply chain decision variables.

T_{s_t} : The green technology level of the supplier in period t

T_{m_t} : The green technology level of the manufacturer in period t

For the *supplier's* green technology level,

$$0 \leq T_{s_t} \leq 1$$

$$T_{s_t} = \begin{cases} 0, \text{minimum green technology level is achieved in period t by the supplier} \\ 1, \text{maximum green technology level is achieved in period t by the supplier} \end{cases}$$

For the *manufacturer's* green technology level,

$$0 \leq T_{m_t} \leq 1$$

$$T_{m_t} = \begin{cases} 0, \text{minimum green technology level is achieved in period t by the manufacturer} \\ 1, \text{maximum green technology level is achieved in period t by the manufacturer} \end{cases}$$

Green technology is defined as the emissions-reducing technology (Krass et al., 2013). The previous section has explained that green technology level is measured by the car's fuel efficiency in this study. Fuel efficiency is often known as a car's miles per gallon or litres per kilometre. When the maximum green technology level is made by both supplier and manufacturer, the car has the highest achievable fuel efficiency (lowest emission level). In contrast, when both supplier and manufacturer only reach the minimum green technology level, the car has the lowest possible fuel efficiency and the highest emission level.

$$\text{Gar greenness:} \begin{cases} T_{m_t} = 0, T_{s_t} = 0, \text{minimum car greenness is reached} \\ T_{m_t} = 1, T_{s_t} = 1, \text{ maximum car greenness is reached} \end{cases}$$

6.2.3 Incentive review and adjustment

I Green technology incentive rates in the supply chain

The focus of this research enquiry is the incentive-driven green technology level increase occurring in the supply chain. The core of the government's green incentive project is to encourage supply chain parties to invest in green technology innovation so that product greenness can be enhanced. The incentive rate is given periodically, and supply chain parties are expected to achieve a certain green technology level in each funded period. The supply chain green technology level based on incentives has been selected in this study for investigation.

The initial incentive rate is given by the government as a condition in the incentive project. The incentive rate is a percentage of the proposed incentive project's budget of a supply chain party, and is adjustable based on the project periodically review. When the supply chain implements the incentive project, the government expects the green technology development to progress gradually in each period. Each period is expected to have a certain degree of green technology innovation according to the proposed green technology implementation steps in the incentive project. Initial incentive rates are given to the supplier and manufacturer as $G_{s_{t=0}}$ and $G_{m_{t=0}}$ where each has a corresponding green technology level $T_{s_{t=0}}$ and $T_{m_{t=0}}$ to achieve by the supply chain party.

G_{s_t} : The incentive rate provided to the supplier at period t

G_{m_t} : The incentive rate provided to the manufacturer at period t

II Review of incentive project

According to the interview data, the government accepts applications for technology incentives, such as Industry Technology Development Program (Section industry professionals) (Taiwan Ministry of Economic Affairs, 2011) and Small Business Innovation Research Program (SBIR) (Taiwan Small and Medium Enterprise Administration, 2016) in the background case of Taiwan. An initial incentive rate for the project will be given to the supplier and manufacturer. In their interview, interviewee no.7 stated that "*Last year, the government reduced the percentage of the incentive in the budget of the technology project after the substandard periodical review*." This is identified as "incentive rate adjustment" from Preliminary Study 2.

It is confirmed by the content of the incentive policy and the interview data in Preliminary Study 2 that a technology review focuses mainly on the difference in green technology level between the current and last periods. According to an interview quotation, "*The government looked at our green technology at the end of each term and compared it with the previous period. The review is basically dependent on whether we have better or worse green technology in the current term.*"

The technology review is based on two factors that are formulated with the sensitivity of the green technology level change on incentive rate adjustment, and the amount of change between the previous and present periods. ε_s and ε_m are the sensitivities of green technology change for the supplier and manufacturer, and they are two parameters given by the government. The government review functions are based on the "*the application of qualitative data 2" and "the application of qualitative data 4*" in Preliminary Study 2.

$\mathrm{R}_{\mathrm{s}_t}$: The green technology review for the supplier at period t

$\mathrm{R}_{\mathrm{m}_t}$: The green technology review for the manufacturer at period t

ε_s : The sensitivity of the green technology level change on incentive rate adjustment for the supplier

ε_m : The sensitivity of the green technology level change on incentive rate adjustment for the manufacturer

Incentive adjustment for the supplier (green technology level dependent):

$\mathrm{Rs}_t = \varepsilon_s * (Ts_t - Ts_{t-1})$

Incentive adjustment for the manufacturer (green technology level dependent):

$\mathrm{Rm}_t = \varepsilon_m * (Tm_t - Tm_{t-1})$

Subject to,

$\mathrm{R}\,i_t = [-1,1]$, for t = 1,…, N, *i*= s, m

III Incentive rate with adjustment

The incentive rate of this period is based on the incentive rate of the previous period plus a rate adjustment. When the green technology level is higher than the previous period, the adjustment is a positive value and the incentive rate increases. When the green technology level is lower than the previous period, the adjustment is a negative value and the incentive rate decreases. Incentive rate functions are based on the "*the application of qualitative data 4* " in Preliminary Study 2.

The incentive rate at period t+1 for the supplier:

$G_{s_{t+1}} = G_{s_t} + \mathrm{R}_{\mathrm{s}_t} = G_{s_t} + [\varepsilon_s * (Ts_t - Ts_{t-1})]$

$0 \le Gs_{t+1} \le 1$, for t = 0, …, N

The incentive rate at time t+1 for the manufacturer:

$$G_{m_{t+1}} = G_{m_t} + \mathrm{R}_{\mathrm{m}_t} = G_{m_t} + [\varepsilon_m * (Tm_t - Tm_{t-1})]$$

$0 \le Gm_{t+1} \le 1$, for t = 0, …, N

Technology innovation incentives rate, an example from the interview: HAITEC

According to HAITEC, the example company in the interview, the initial incentive rate was 14%. $Gs_{t=1}$ = 14% (The incentive rate announced at the beginning of the project will be applied to period 1), and it was 8% in period 2, 14% in period 3 for HAITEC. The incentive rate of period 2 depends on the green technology evaluation at the end of period 1; The incentive rate of period 3 is dependent on the review outcome of period 2. The incentive rate in period t depends on the incentive rate and the green technology evaluation in period t-1. Hence, the better the green technology review at the end of the previous period, the higher the incentive rate given to the supply chain party in the present period.

$$G_{m_{t=1}} = 14\%$$
$$G_{m_{t=2}} = G_{m_{t=1}} + \mathrm{R}_{\mathrm{m}_{t=1}} = 14\% + \mathrm{R}_{\mathrm{m}_{t=1}} = 8\%$$
$$G_{m_{t=3}} = G_{m_{t=2}} + \mathrm{R}_{\mathrm{m}_{t=2}} = 8\% + \mathrm{R}_{\mathrm{m}_{t=2}} = 14\%$$
$$\vdots$$
$$G_{m_t} = G_{m_{t-1}} + \mathrm{R}_{\mathrm{m}_{t-1}}$$

If there is no change to the green technology level between period t-1 and t, the company remains at the same level of green technology. The incentive rate for this period is kept the same as the previous one.

For the supplier:

When $Ts_t = Ts_{t-1}$

$$\mathrm{R}_{\mathrm{s}_t} = \varepsilon_s * (Ts_t - Ts_{t-1}) = \varepsilon_s * 0 = 0$$
$$G_{s_{t+1}} = G_{s_t} + \mathrm{R}_{\mathrm{s}_t} = G_{s_t} + [\varepsilon_s * (Ts_t - Ts_{t-1})] = G_{s_t} + 0 = G_{s_t}$$

For the manufacturer:

When $Tm_t = Tm_{t-1}$

$\mathrm{R}_{m_t} = \varepsilon_m * (Tm_t - Tm_{t-1}) = \varepsilon_m * 0 = 0$

$G_{m_{t+1}} = G_{m_t} + \mathrm{R}_{m_t} = G_{m_t} + [\varepsilon_m * (Tm_t - Tm_{t-1})] = G_{m_t} + 0 = G_{m_t}$

If there is a change to the green technology level between period t-1 and t:

For the supplier:

- When the green technology level is higher than the previous period, $Ts_t - Ts_{t-1} > 0$, $Rs_t > 0$, and $Gs_t > Gs_{t-1}$, the incentive rate increases in the following period
- When the green technology level is lower than the previous period, $Ts_t - Ts_{t-1} < 0$, $Rs_t < 0$, and $Gs_t < Gs_{t-1}$, the incentive rate decreases in the following period

For the manufacturer:

- When the green technology level is higher than the previous period, $Tm_t - Tm_{t-1} > 0$, $Rm_t > 0$, and $Gm_t > Gm_{t-1}$, the incentive rate increases in the following period
- When the green technology level made is lower than the previous period, $Tm_t - Tm_{t-1} < 0$, $Rm_t < 0$, and $Gm_t < Gm_{t-1}$, the incentive rate decreases in the following period

6.2.4 Market demand

I Consumer demand

The literature and the interviews (*application of qualitative data 1* and *application of qualitative data 2* in Preliminary Study 2) both suggest that demand for green cars is influenced by price and green technology adoption (Pickett-Baker & Ozaki, 2008; Lee et al., 2013). Firstly, a car's greenness impacts on car sales. According to an interviewee quotation: *"Customers are buying green cars to save the fuel cost of future use"*. Greener cars have higher fuel efficiency, and this indicates the importance of green technology when a consumer buys a car. Secondly, price is also important when buying cars. An interviewee said: "*Customers care about the price very much because normally, green cars are slightly more expensive than non-green cars, so they buy more when the price is low. For example, there was a decrease in green car sales in 2014 because the overall market price went up a little bit without government incentives*". According to interview data and the literature, both car greenness and price are taken into consideration in the function of cars' demand.

Because product price and green technology level are considered to be the two key determinants for the demand for green cars in the Taiwanese market, both have been included in the present model. This study assumes that the foundation of the demand function is led by market size and price. This assumption has been widely used in the field of supply chain strategy since Abad (1994) introduced the supplier pricing game model with a price-sensitive linear demand function. Notably, in the green car market, consumers tend to purchase green products from greener companies (Pickett-Baker & Ozaki, 2008) and they prefer cars with lower emissions (Daziano & Bolduc, 2013). Thus, it is believed that product greenness relates to consumers' willingness to buy the product. The influence of product greenness on demand indicates consumers' green preferences. Consumers increase their willingness to buy the product when the greenness of a product rises, in terms, for instance of decrease in emission and/or increase in fuel efficiency, and this is confirmed in "*application of qualitative data 2*" in Preliminary Study 2. The market demand is the sum of the base demand from ordinary consumers and the greenness dependent demand from green consumers (Nouira et al., 2014; Letmathe & Balakrishnan, 2005). Peng (2013) and Nouira et al. (2014) have added the degree of sustainability for green products in the linear price dependent function to explain consumers' green preference. Following the above demand functions in Abad (1994), Cohen et al. (2015), Nouira et al. (2014) and Peng (2013), this study adopted a linear demand which depends on price and car greenness:

$$Demand = a - bp + c\left(\alpha T_{s_t} + \beta T_{m_t}\right)$$

a: Market size

b: The factor of the price on market demand indicates the sensitivity of demand as the price changes. Consumers' preferences are different from time to time. The importance of price for hybrid car buyers depends on purchasing power. For instance, the price may become more influential on consumer behaviour when a country has a negative growth of GDP.

c: The value of *c* represents the influence of car greenness on demand, which is also one of the random factors in the model. With the rise of environmental awareness, parameter c will increase in order to reflect consumer preference, as indicated by interviewee no. 1 "*The importance of green technology is actually changing every* *year. Sometimes, customers care more about car greenness because they want to be environmentally friendly and/or save money on fuel. Sometimes they care less about car greenness because they are sensitive to price*."

II The effect of consumer incentives on car demand

Incentives on the green product, such as tax reduction for consumers, are identified in the interviews. However, consumer incentive remains constant regardless of car model (as long as it is a green car). The competition between green and non-green vehicles is not the research focus in the current model, and therefore, consumer incentive is not considered to be a factor determining the market demand.

6.2.5 Supply chain objectives

I Green technology costs

To achieve a certain level of green technology level, both the supplier and manufacturer have a fixed cost and a variable cost (Krass et al., 2013). These costs depend on the green technology level. In the car industry, variable cost is determined by the material directly used to produce the car. A car of a higher green technology level usually requires more special parts. Because the cost of new parts causes an increase in the marginal cost, it is assumed that the relationship between green technology level and variable cost is positively linear. In addition to the variable cost, the fixed cost for green technology adoption is often known as the investment in a new production line. According to an interviewee quotation, "*We have to buy new machines to adopt in the production line for the green technology innovation; usually they are expensive because green cars' process of assembly is totally different from traditional cars*". In the present model, it is assumed that fixed cost is the cost of *technology change*, that is, both the increase and decrease of the green technology level will cause a fixed cost. *Changing cost* involves upgrading to a greener machine for the product line, the cost of seeking new material, components, and machine supply. In a word, the fixed cost depends on the change of green technology level between the previous and the current period, and there is a quadratic dependence formulated below.

II Supply chain costs without government incentives

For the *supplier*, technology cost is presented below:

The variable cost at the level T_{m_t} for the manufacturer: $T_{m_t} C_m$

The fixed cost at the level T_{m_t} for the manufacturer: $(T_{m_t} - T_{m_{t-1}})^2 C_d$

$$T_{s_t} - T_{s_t - 1} : \left\{ \begin{array}{l} > 0,\ \text{variable cost increases, fixed cost increases} \\ = 0,\ \text{variable cost remains the same, no fixed cost} \\ < 0,\ \text{variable cost decreases, fixed cost increases} \end{array} \right\}$$

For the *manufacturer*, technology cost is presented as below:

The variable cost at the level T_{s_t} for the supplier: $T_{s_t} C_s$

The fixed cost at the level T_{s_t} for the supplier: $(T_{s_t} - T_{s_{t-1}})^2 C_f$

$$T_{m_t} - T_{m_t - 1} : \left\{ \begin{array}{l} > 0,\ \text{variable cost increases, fixed cost increases} \\ = 0,\ \text{variable cost remains the same, no fixed cost} \\ < 0,\ \text{variable cost decreases, fixed cost increases} \end{array} \right\}$$

III Supply chain costs with government incentives

G_{s_t} and G_{m_t} are the incentive rates for the supplier and the manufacturer from the government that indicate the percentage of the green technology development costs covered by the government. The relevant costs are presented below,

For the *supplier*,

The variable cost with green technology level T_{s_t} given the government incentives:

$T_{s_t} C_s * (1 - G_{s_t})$

The fixed cost with green technology level T_{s_t} given the government incentives:

$(T_{s_t} - T_{s_{t-1}})^2 C_f * (1 - G_{s_t})$

For the *manufacturer*,

The variable cost with green technology level T_{m_t} given the government incentives:

$T_{m_t} C_m * (1 - G_{m_t})$

The fixed cost with green technology level T_{m_t} given the government incentives:

$(T_{m_t} - T_{m_{t-1}})^2 C_d * (1 - G_{m_t})$

IV Greenness of the car

The greenness of a car indicates its overall level of green technology adoption, as noted by an interviewee: "A *greener car means it has higher green technology and can help more with carbon emission reduction on the Earth"*. That is, the higher the greenness level of a car, the less emission this car produces.

αT_{s_t}

The greenness of a car is determined by the aggregation of green technologies in the supply chain, which includes that of suppliers' and the manufacturers'. This can be illustrated by a practice case from Nissan. To quote from an interview: "*To have a greener car, we need to find the right motor, battery, and even the engine for the new car's design*". Nissan attempted to design a more energy efficient electric hybrid vehicle. In order to do that, they needed a suitable engine. The manufacturing of the suitable engine by their supplier involved the selection of raw material and assembling sub/minor parts into ready-to-use components. This example suggests that the supplier can influence the greenness of a car. Nissan's manufacturer only selected the engine from suppliers who can meet their requirements, and adapted it to their engine system. The hybrid car's energy conversion and storage system were subsequently designed by Nissan (manufacturer) in order to link engine, battery and motor. To summerise, the supplier's green technology affects the key components supplied to the manufacturer such engine, battery and motor. The manufacturer's green technology affects the design of the car system such as car's integration system, charging system, pumped storage system, and the drive system. In the green car production process, therefore, both the supplier and the manufacturers play an important role in determining the greenness of a car.

Furthermore, it is confirmed in the *application of qualitative data 2* in study 2 that the final car greenness is reflected both by the supplier and the manufacturer's green technology. It is assumed therefore, that a car's greenness is the combination of the supplier's and manufacturer's green technology level.

Product Greenness = $\alpha T_{s_t} + \beta T_{m_t}$

α: The weight of the suppliers' green technology's impact on car greenness
β: The weight of the manufacturer's green technology's impact on car greenness

$\alpha + \beta = 1$

$0 \leq \alpha \leq 1$

$0 \leq \beta \leq 1$

The influence of the interaction between suppliers' and manufacturers' green technology level on the final greenness of a car is not considered for two reasons. First, suppliers and manufacturers make decisions regarding their green technology level independently. A manufacturer noted in the interview: "*We have been applying the government incentive project for many years, sometimes we know our supplier also applies it but they wouldn't share the project's content with others because it's classified*". It shows that when the government provides incentives to the supplier and the manufacturer at the same time, the green technology decision is affected by the orientation of profit maximisation, rather than by each other's decision. Secondly, assuming that the manufacturer is aware of the supplier's green technology level, expectedly the manufacturer's decision will still be independent of the supplier's decision. It has been confirmed that the effect of green policy on green technology innovation is influenced by the innovation cost (Fischer et al., 2003). The objective for the manufacturer is profit maximisation; and for this reason, the manufacturer's optimal decision of green technology level is based on the cost of relevant technology and the government's incentive instead of the supplier's green technology level. To conclude, the interaction between the supplier and manufacturer's green technology decision is not considered to be a significant influence in the model.

V Supply chain objective functions

It is confirmed in the interview data (*application of qualitative data 3* in Preliminary Study 2) that the objective of supply chain parties is profit maximisation. The objective functions are presented below.

- Supplier

  For the supplier, the objective is to maximise its own profit:

  Max. Profit = (Product wholesales revenue – variable cost of manufacturing given the government incentives) * (market demand)-fixed cost of green technology given the government incentives

  Max.

$$\pi_{s_t}\left(w_t, T_{s_t}\right) = \left(w_t - T_{s_t} C_s (1 - G_{s_t})\right)\left(a - bp_t + c\left(\alpha T_{s_t} + \beta T_{m_t}\right)\right) - (T_{s_t} - T_{s_{t-1}})^2 C_f (1 - G_{s_t})$$

  Subject to

$$w_t \geq 0$$

$$T_{s_t} \geq 0$$

$$a - bp_t + c\left(\alpha T_{s_t} + \beta T_{m_t}\right) \geq 0$$

- Manufacturer

  For the manufacturer, the objective is to maximise its own profit:

  Max. Profit = (sale revenue–wholesale price- variable cost of manufacturing given the government incentives) * (market demand) – fixed cost of green technology given the government incentives

  = Max.

$$\pi_{m_t}\left(p_t, T_{m_t}\right) = \left(p_t - w_t + T_{m_t} C_m (1 - G_{m_t})\right)\left(a - bp_t + c\left(\alpha T_{s_t} + \beta T_{m_t}\right)\right) - (T_{m_t} - T_{m_{t-1}})^2 C_d (1 - G_{m_t})$$

Subject to

$$p_t \geq 0$$

$$T_{m_t} \geq 0$$

$$a - bp_t + c\left(\alpha T_{s_t} + \beta T_{m_t}\right) \geq 0$$

6.2.6 Government objectives

According to the discussion in section 6.1.2, the government's objective is divided into three parts, such as environmental impact, supply chain profit, and consumers' benefits from the government incentives to the supply chain.

I. Consumer benefit from the government incentives to the supply chain

It has been confirmed by interview data (Preliminary Study 2) that the incentive has a positive effect on green technology innovation: Quotation of the interview "*the incentives help us to invest in green technology with a lower cost because part of the cost is covered by the incentives.*" With the green incentives, the supply chain provides a greener product without reflecting all the increased cost on the product price, and even lower the price of the green product. Price may fall when the incentive increases because incentives offset part of the technology cost. Since the price and the greenness of a product are changed by the government incentive to the supply chain, consumers receive benefit from these changes. In other words, a consumer is expected to be provided greener products and experience a reasonable price change. As an extended benefit of the incentive, the government also takes consumers' benefit into consideration when providing incentives to the supply chain. The consumer's benefit resulted from the government's supply chain incentive having two parts including the benefit from the change of product greenness and the benefit from the change of price. The consumer's benefit (B_c) is evaluated as part of the government's objective in the model. B_c= "The change of product greenness in period t" plus "The change of price in period t"

The change of product greenness in period t :

Car greenness of the current period – Car greenness of the previous period

$$\left(\alpha T_{s_t} + \beta T_{m_t}\right) - \left(\alpha T_{s_{t-1}} + \beta T_{m_t-1}\right)$$
$$= \alpha (T_{s_t} - T_{s_{t-1}}) + \beta (T_{m_t} - T_{m_t-1})$$

The change in price in period t : $p_t - p_{t-1}$

II. Supply chain profit

Supply chain profit includes the profit of the supplier and the manufacturer:

$$\pi_{s_t}\left(w_t, T_{s_t}\right) = \left(w_t - T_{s_t} C_s (1 - G_{s_t})\right)\left(a - bp_t + c\left(\alpha T_{s_t} + \beta T_{m_t}\right)\right) - (T_{s_t} - T_{s_{t-1}})^2 C_f (1 - G_{s_t})$$

$$\pi_{m_t}\left(p_t, T_{m_t}\right) = \left(p_t - w_t + T_{m_t} C_m (1 - G_{m_t})\right)\left(a - bp_t + c\left(\alpha T_{s_t} + \beta T_{m_t}\right)\right) - (T_{m_t} - T_{m_{t-1}})^2 C_d (1 - G_{m_t})$$

III. Environmental impact

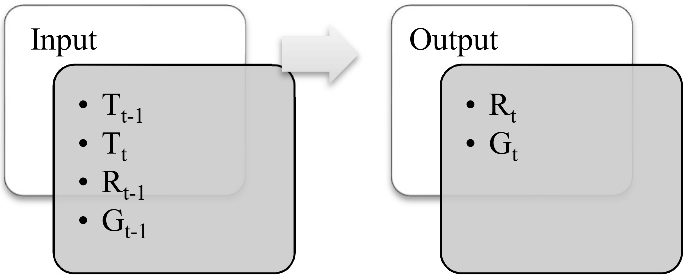
Emissions produced during the use of cars is evaluated by the government as an environmental impact indicator. In the present model, it is assumed that e_m is the factor of the influence of car greenness on emission produced from product use, and the actual emissions are dependent on car greenness which is the decision variable of the supplier and the manufacturer. The higher the car greenness, the lower the emissions. Total emission equates to total demand multiply emission produced per unit. When there is only a minimum green technology development made by the supply chain, the total emissions produced from the product use is a maximum value. This project will evaluate the output of green technology level and the market demand to represent the discussion of the emissions. When there is a green technology innovation/improvement made by either the supplier or the manufacturer, the total emissions is dependent on the green technology level and the total car demand.

The emission produced during the "production process" is not considered in this model because the Taiwanese government has not issued a green policy regarding the emissions in the supply chain. Although there are suggested maximum emission allowances for the manufacturing process of car companies, no actual punishment would be given to regulate production emissions. Hence, emission as a result of the production process is only taken as the "next step" of the government's green intervention to the car industry in Taiwan, and it is considered as a constituent of further research.

IV The multiple-period problem for the government

Based on the mechanism of the government incentive and Preliminary Study 2's interview data from the car industry in Taiwan, this study formulates the government's function in two parts, one being the incentive rate and technology review, and the other the incentive rate adjustment.

Input and output variables for the government at period t :



**T=green technology level, R=Technology review, G=Incentive rate*

6.2.7 Optimal pricing and technology level decisions in the supply chain

Maple 16 is used for the optimisation of the problem-solving process. In the two-stage game model, the backward induction is conducted to obtain the optimal solution. There are two stages of decision making in the green product incentive model. The manufacturer makes the decision after the supplier has made it. Thus, to gain the optimal solutions, this study solves from the manufacturer and back to the supplier as stage 1 and 2.

Stage 1. Optimal solutions of the manufacturer

The manufacturer has decision variables with product price p and the green technology level T_m ; all other parameters are considered as known while the manufacturer makes the decision. The manufacturer's profit maximisation problem can be illustrated as below:

$$Max$$

$$\pi_m\left(p,T_m\right)=\left(p-w+T_m Cm(1-G_m)\right)\left(a-bp+c\left(\alpha T_s+\beta T_m\right)\right)-(Tm-Tmt)^2 * C_{tm}(1-G_m)$$

(1)

Subject to:

$p \geq 0$

$T_m \geq 0$

$a - bp + c(\alpha T_s + \beta T_m) \geq 0$

Theorem 3. There is a unique optimal strategy including the product price and the green technology level of the manufacturer in this model. The optimal solution maximises globally the manufacturer's profit in the supply chain model. See the proof of negative definition in the Hessian matrix in the Appendix.

The problem-solving process of the unique optimal pricing and technology level decisions is summarised as follows:

Assume that the manufacturer makes the product price in the market p and green technology level T_m. The manufacturer pays the wholesale price w and considers a green technology variable cost C_m and fixed cost C_{tm} to maximise its profit, which is equation (1).

Equating first partial derivative of $\pi_m(p, T_m)$ with respect to p, T_m to zero, it obtains:

Subject to $p \geq 0$, $T_m \geq 0$, $a - bp + c(\alpha T_s + \beta T_m) \geq 0$

$$-bp + a + c(\alpha Ts + \beta Tm) - (p - w - TmCm(1 - Gm))b$$

(2)

$$-Cm(1 - Gm)(-bp + a + c(\alpha Ts + \beta Tm)) + (p - w - TmCm(1 - Gm))c\beta - 2TmCtm(1 - Gm)$$

(3)

By collecting terms in equation (2), given T_s, T_m and w, the optimal price is obtained as:

$$p^*(T_m,T_s,w)=\frac{Cm(1-Gm)Tmb+Tm\beta c+Ts\alpha c+bw+a}{2b} \tag{4}$$

Substituting equation (2) in equation (3) and solving this equation equaling 0, given w and T_s and satisfying the condition of $Tm > 0$, it obtains the optimal solution of Tm :

$$Tm^*(w,T_s)=-\frac{\alpha\beta Tsc^2-\alpha Cm(1-Gm)Tsbc-\beta bcw+Cm(1-Gm)b^2w+\beta ac-Cm(1-Gm)ab}{\beta^2c^2-4\beta Cm(1-Gm)bc-Cm(1-Gm)^2b^2-4Ctm(1-Gm)b} \tag{5}$$

In addition, taking the Tm^* into equation (4), and given w and T_s, the optimal solution of p^* is shown as:

$$p=\left(-Cm(1-Gm)^2\,Ts\,\alpha\,b\,c+Cm(1-Gm)\,Ts\,\alpha\,\beta\,c^2+Cm(1-Gm)\,b\,\beta\,c\,w-\beta^2c^2w+2\,Ctm(1-Gm)\,Cm(1-Gm)\,Tmt\,b+2\,Ctm(1-Gm)\,Tmt\,\beta\,c+2\,Ctm(1-Gm)\,Ts\,\alpha\,c-Cm(1-Gm)^2\,a\,b+Cm(1-Gm)\,a\,\beta\,c+2\,Ctm(1-Gm)\,b\,w+2\,Ctm(1-Gm)\,a\right)\Big/\left(-Cm(1-Gm)^2\,b^2+2\,Cm(1-Gm)\,b\,\beta\,c-\beta^2c^2+4\,Ctm(1-Gm)\,b\right) \tag{6}$$

<u>Stage 2. Optimal solutions of the supplier</u>

Assume that the supplier decides the wholesale price charged to the manufacturer w and green technology level T_s . The supplier has production cost C_s and green technology improvement unit cost C_{ts} to maximise its own profit. Thus, the objective profit function of the supplier will be:

$$Max\quad \pi_s(w,T_s)=\left(w-T_sC_s(1-G_s)\right)\left(a-bp^*+c\left(\alpha T_s+\beta T_m^*\right)\right)-(Ts-Tst)^2C_{ts}(1-G_s)$$

(7)

Substituting p^*, T_m^* which is obtained from stage 1 for the supplier's objective function in equation (7),

Max

$$\frac{2\left(w-TsCs\left(1-Gs\right)\right)Ctm\left(1-Gm\right)b\left(Cm\left(1-Gm\right)Tmtb-Tmt\beta c-Ts\alpha c+bw-a\right)}{Cm\left(1-Gm\right)^2 b^2-2Cm\left(1-Gm\right)b\beta c+\beta^2 c^2-4Ctm\left(1-Gm\right)b}-\left(Ts-Tst\right)^2 Cts\left(1-Gs\right) \quad (8)$$

Subject to:

$w \geq 0$, $T_s \geq 0$, $a-bp+c\left(\alpha T_s+\beta T_m\right)\geq 0$

Theorem 4. It is confirmed that a unique optimal solution exists, including the wholesale price and green technology level of the supplier. Also, the optimal solution maximises globally the supplier's profit in the supply chain model. See the proof of negative definition in the Hessian matrix in the Appendix. Also, due to the word limit of this thesis, the optimal solution of the wholesale price and the green technology level for the supplier are presented in the Appendix.

6.2.8 Model assumptions

- The government incentives to the supplier and the manufacturer are limited.
- The car emission level is based on car greenness: the higher a vehicle's greenness, the lower the vehicle's GHG emission.
- The greenness of a product depends on the supplier's green technology level and the manufacturer's green technology level.
- Market demand increases when the green level of a product increases, and there is a linear relationship with the demand to the price and the greenness of the product.

- Perfect information game model is adopted between the supplier and the manufacturer as there is commonly a vertical integration between the supplier and manufacturer in the car industry.
- The market structure is a monopoly; the other's pricing decision is considered as given and the influence of the monopolist's own price on others' pricing strategy is ignored.
- There are one main supplier and one main manufacturer in the car supply chain.
- The government only focuses on the emissions produced by consuming/using the product but not the overall product life cycle.
- The technology variable cost has a linear relation with green technology level and the fixed cost is also linearly dependent on the green technology level for both supplier and manufacturer.

6.2.9 Simulation model

I Uncertainty of the simulation model

Consumers' sensitivity to price

The price of a product is often a key factor affecting consumers' purchasing behaviour. Price sensitivity is defined as consumers varying their decision of product purchase when the product price changes (Tellis, 1988). Price sensitivity can differ between individuals, or when the environment changes such as from offline to online (Degeratu, Rangaswamy, & Wu, 2000). The economic environment also affects consumers' price sensitivity because it relates to what consumers can afford. For example, consumers are more sensitive to price when an economic crisis occurs, but they are less price-sensitive when their financial status is good. Thus, in the incentive model of this study, price sensitivity is considered as an uncertain factor which moderates the market demand.

Consumers' sensitivity to green technology level

It was indicated in the literature, that green car demand is influenced by price and green technology adoption (Pickett-Baker & Ozaki, 2008; Lee et al., 2013) so the sensitivity of consumers' green preference is also considered in the simulation model. In the market, some green consumers prefer to buy the green product and non-green consumers who have less interest in buying green products. It was noted in Preliminary Study 2 that consumers' response to car greenness changes over time. This change is affected by the market environment, and it is also dependent on consumers' environmental awareness and other concerns. Therefore, because it significantly changes the market demand, this study takes consumers' sensitivity to the green technology level of green cars into account when building the simulation model.

II Distribution of random variables

The distributions of two random variables (price sensitivity and technology sensitivity) in the simulation model are based on the coefficients of car sales regression model. The car sales data used in this project has been collected in Taiwan between 2011 and 2015. The data includes car brands, car models, car sales, car prices, and unit fuel consumption (LTR). The data has been obtained from the Ministry of Transportation and Communications, Directorate General of Highways (MOTC) in Taiwan. To build the distribution of these two variables, price and technology sensitivity are revealed by the coefficients *of car price* and the *fuel efficiency* from the regression model. It was indicated in the qualitative date in Study 2, fuel efficiency is the level of energy-saving that represents the green technology level (obtained from interview). Thus, an average *litre per kilometre* (LTR) is used to indicate car greenness in the analysis in the regression.

Table 12 - Example data used for generating the distribution of uncertainties

Car brand	Car model	Price	Fuel consumption km/ltr (LTR)	Sales					
				Jan. 2015	Feb. 2015	Mar. 2015	Apr. 2015	May 2015	Jun. 2015
LUXGEN	LUXGEN U6 2.0 A6	959,000	13.5	689	272	400	302	375	369
TOYOTA	CAMRY HYBRID G	1069,000	19.6	312	153	272	235	178	186
MITSUBISHI	OUTLANDER PHEV HYBRID 2.0 A1 5D	979,000	15.8	433	151	210	221	124	173

*price is shown in TWD

Regression model of the sales

A regression model was used to predict electric vehicle adoption (sales) in Norway (Mersky et al., 2016) and Malaysia (Sang & Bekhet, 2015). It is a suitable approach to analyse the market demand (Cohen et al., 2013) and it has been applied in operation management research (Flammer, 2015; Koumanakos, 2008). Thus, regression analysis has been selected here to present the demand function in the incentive model to confirm the relationship between the variables of price, car greenness and market demand.

Dependent variable: Market demand (Q)

The market demand is revealed by the total quantity of cars purchased by consumers.

Independent variables: Price (p) and Green technology level (T_m, T_s)

The green car demand is determined by several factors such as car selling price, the expected operating costs in the future and the number of charging stations (Yu et al., 2015). Comparing the literature and the semi-structure interviews in Taiwan, this study listed the following factors to be considered in the regression model.

- Price: β_1

Market price has a key impact on consumer preference and thus affects market demand (Wu et al., 2009). In Taiwan, consumers face a high price as the main problem in affording green cars. Although consumer incentives help, there is still a significant price difference between grey and green vehicles in the Taiwanese market.

- Car greenness: β_2

Higher greenness level leads to more car sales in the market (Lee et al., 2013) because greener products are not only environmentally friendly but they can also help reduce future energy cost. For example, the better the green technology of a car's engine system, the higher its energy efficiency, and thus the less its future use will cost. Therefore, car greenness is believed to be an important variable when forecasting green car demand. In the model, car greenness is indicated by a car's fuel consumption. That is, a high level of car greenness has higher fuel efficiency and less fuel consumption. Fuel consumption in the car data is presented as average unit fuel consumption, LTR (km/litre).

Applying the regression model in linear demand function

In the simulation model, a linear market demand function based on Abad's (1994) work is adopted. Similar to Abad (1994), Peng (2013) proposed a green product demand which is dependent on market size, product price and product greenness. This study follows Abad (1994) and Peng (2013), a linear demand function is presented as: $Demand = a - bp + cT$, $T = \alpha T_s + \beta T_m$, a is the market size, p is price and T is overall car greenness which is the sum of the supplier's and the manufacturer's green technologies. Factor b is the sensitivity of price and c is the sensitivity of green technology in the demand function.

Demand function: $Demand = a - b * p + c * T = -b * p + c * T + a$

Regression model based on sales: $Sales = \beta_1 * p + \beta_2 * T + \varepsilon$

β_i : The correlation coefficients for each independent variable, i=1, 2

ε : The constant

In this model, the correlation coefficient of price β_1 in the sales regression model is used to indicate the sensitivity of price $-b$ in the demand function. The correlation coefficient of price β_2 in the sales regression model is used to represent the sensitivity of price c in demand function. β_1 and β_2 are taken to examine the relationship between price and car sales, and the relationship between car greenness and sales.

Table 13 - Example input data of the January 2011 (period 1)

Car model	Price	LTR	Sales	Car model	Price	LTR	Sales	Car model	Price	LTR	Sales
1	57.9	16.8	1185	33	88.9	11.8	298	65	87.9	12.3	9
2	93.5	12.5	49	34	83.9	11.8	310	66	81.5	12.9	5
3	66.9	15.4	428	35	62.9	11.1	540	67	71.9	15.5	71
4	77.9	15.4	802	36	85.9	10.4	191	68	71.5	15.5	119
5	80.9	14.3	132	37	62.9	14.5	715	69	81.9	12.5	45
6	77.9	12.4	608	38	65.9	18.2	4997	70	82.9	12.6	81
7	54.8	12.1	402	39	93.9	18.1	71	71	60.9	12.9	249
8	91.5	11.6	25	40	82.9	17.7	209	72	54.5	11.3	705
9	95.5	11.6	13	41	88.9	17.7	75	73	76.9	15	274
10	69.3	11.6	221	42	71.9	12.3	1107	74	63.9	15.4	452
11	65.9	11.4	633	43	75.5	12	747	75	56.9	15.4	1906
12	88.5	10.5	54	44	51.9	11.9	600	76	119.9	9.5	11
13	59.5	10.8	645	45	151	11.4	18	77	109.9	9.5	24
14	77.9	10.2	270	46	121	11.7	29	78	165	10	28
15	62.5	12.8	392	47	102.9	18.2	1	79	62.5	12.7	680
16	78.7	12.8	232	48	65.9	17.4	1129	80	73.9	12.3	276
17	78.5	16.2	125	49	48.9	17.4	688	81	84.9	11.1	37
18	78.5	16.2	91	50	56.8	13.7	1384	82	62.5	15	1990
19	70.6	16.2	314	51	60.8	13.3	121	83	39.9	15.3	299
20	88.9	11.5	81	52	56.8	13.7	738	84	41.5	16	747
21	70.6	11.5	202	53	39.8	16.5	494	85	140.9	14	62
22	99.9	11.2	7	54	66.9	16.6	1797	86	94.9	14.2	40
23	87.5	12.4	55	55	98.9	15.5	58	87	105.9	9.5	0
24	105.9	16.5	9	56	53.3	12.8	314	88	92.5	9.5	0
25	72.9	16.5	126	57	59.9	12.9	369	89	109	9.5	149
26	95.9	12.4	57	58	63.5	13.1	212	90	52.9	9.5	344
27	132.9	11.8	1	59	61.9	12.9	465	91	100	9.5	172
28	97.9	11.8	87	60	67.9	12	59	92	39.9	9.5	336
29	113.9	9.9	15	61	99.9	12.4	5	93	63	9.4	773
30	78.9	13.4	201	62	52.9	12	527	94	62.5	9.4	1163
31	65.9	13.4	458	63	87.5	12.6	2	95	67	8.4	314
32	96	12.4	25	64	78.9	12.3	6				

Result

A multiple regression model was conducted to predict car sales based on the price and greenness. There are 60 periods sales data used, thus 60 regression models are calculated to generate the distribution in the next section. To avoid repetitions, this study presents the example of the regression model in observed period 1. A significant regression equation was performed F (2, 92) = 11.767, $p < .05$, with an R^2 of 0.204, adjusted R^2 is 0.186. It was found that two independent variables, price and car greenness can significantly predict car sales. For Price variable, $\beta_1 = -0.338$, $p < .05$; For LTR (Greenness) variable, $\beta_2 = 0.229$, $p < .05$. There is a significant positive relation between car greenness and sales. Also, there is a significant negative relationship between price and car sales.

Regression Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	352.140	428.044		0.823	0.413
Price	-9.245	2.618	-0.338	-3.531	0.001***
LTR	59.595	24.885	0.229	2.395	0.019**

*Dependent Variable: Car sales

The statistical regression result has confirmed the assumption of the linear demand function from the significant positive/negative relationship between the dependent variable (sales) and independent variables (price and car greenness). The above result from the regression model has confirmation two points. First, it is appropriate to apply a linear demand function in the model of this research as the linear regression model is valid to predict car sales by price and car greenness. Secondly, the coefficients of price and car greenness can be used as sensitivities in the simulation model because they are proven to be significantly correlated to sales (demand).

III Generating the distribution of random variables

The regression model revealed coefficients of price and car greenness which represent the sensitivities of these two variables on demand, price sensitivity and green technology sensitivity. Minitab 19 software has been used to produce the distributions of input random variables. There are four steps of computing the distribution of two random variables.

Steps of generating the distributions of price and green technology sensitivities

For price sensitivity:

(1) Input the sales data with two predictors, car price and car greenness level, building regression models for each period from 2011 to 2015.

(2) The price sensitivities factors from 2011 to 2015 will be collected from the coefficients of price variables in regression models.

(3) Input the 60 periods of data into Minitab software and output distribution for the price sensitivity.

(4) Define the range of the distribution according to the result in (3).

For green technology level sensitivity:

(1) Input the sales data with two predictors, car price and greenness, building regression models for each period from 2011 to 2015.

(2) The green technology sensitivities data from 2011 to 2015 will be collected from the coefficients of green technology level variables in regression models.

(3) Input the 60 periods of sales data into Minitab and output distribution for the green technology sensitivity.

(4) Define the range of the distribution according to the result in (3).

Data of Step 1 and Step 2 is obtained from the last regression model in the previous section. The output data of 60 periods which have 60 values for both price sensitivity and green technology level sensitivity. In the Minitab 19, 60 values are input to generate the distribution of the variables, the result is presented below:

Table 14 – The Goodness of Fit Test for distribution identification of random variables

Distribution	AD	P	LRT P
Normal	0.552	0.144	
Box-Cox Transformation	0.237	0.770	
Lognormal	1.078	0.007	
3-Parameter Lognormal	0.219	*	0.004
Exponential	2.462	0.003	
2-Parameter Exponential	2.315	<0.010	0.284
Weibull	0.281	>0.250	
3-Parameter Weibull	**0.273**	**>0.500**	**0.928**
Smallest Extreme Value	2.197	<0.010	
Largest Extreme Value	0.210	>0.250	
Gamma	0.416	>0.250	
3-Parameter Gamma	0.218	*	1.000
Logistic	0.317	>0.250	
Loglogistic	0.623	0.067	
3-Parameter Loglogistic	0.202	*	0.046

Distribution	AD	P	LRT P
Normal	**0.566**	**0.132**	
Box-Cox Transformation	0.566	0.132	
Lognormal	2.215	<0.005	
3-Parameter Lognormal	0.565	*	0.000
Exponential	4.610	<0.003	
2-Parameter Exponential	4.468	<0.010	0.278
Weibull	0.781	0.039	
3-Parameter Weibull	0.591	0.093	0.156
Smallest Extreme Value	1.112	<0.010	
Largest Extreme Value	0.914	0.019	
Gamma	1.292	<0.005	
3-Parameter Gamma	1.251	*	0.016
Logistic	0.513	0.151	
Loglogistic	1.334	<0.005	
3-Parameter Loglogistic	0.510	*	0.001

Identifying the distribution requires to find the highest *p*-value from the distributions in the result table from the Minitab 19 software. It was identified that Price sensitivity follows a 3-Parameter Weibull distribution which has a *p*-value >0.500. The Green technology sensitivity follows a normal distribution which is selected because it has the highest *p*-value among all distributions (p = 0.132). Two transformations are not considered because this study aims to identify nature distribution. For Price sensitivity, the identified 3-Parameter Weibull distribution has a Shape value of 1.66276, a scale of 0.06381, and a threshold of -0.00038. For Green technology sensitivity, identified normal distribution presents a mean value 0.30354 with a standard deviation 0.14114. The information of the distribution is used to generate random values of the Price sensitivity and Green technology sensitivity as uncertainties in the simulation model.

IV Experiment design

The effect of incentive change on the supply chain's decision making is examined by comparing the following design points. Based on the qualitative data obtained in Preliminary Study 2 (*Application of qualitative data 4)*, incentive rates are categorized into "low" and "high" rates. In this project, 20% is considered to be a low incentive rate, whereas 50% is considered to be a high incentive rate. The first combination is "Low Incentives" strategy where both the supplier and the manufacturer are given a low incentive rate. The second combination is the "Supplier Focus" strategy where the supplier is given a high incentive rate, while the manufacturer is given a low incentive rate. The third combination is the "Manufacturer Focus" strategy where the supplier is given a low incentive rate, while the manufacturer is given a high incentive rate. The fourth combination is the "High Incentives" strategy where both the supplier and the manufacturer are given a high incentive rate.

Table 15 – Experiment design of model analysis

Factor Combination (Design point)	Supplier's Initial Incentive Rate	Manufacturer's Initial Incentive Rate	Government Strategy
1	20%	20%	Low Incentives
2	50%	20%	Supplier Focus
3	20%	50%	Manufacturer Focus
4	50%	50%	High Incentives

V Scenario analysis

In each section, a scenario analysis is conducted to predict the supply chain decisions under different scenarios. Two scenarios are considered in this research project as follows.

Scenario 1: High investment cost of green technology development and adoption

This scenario is employed for two reasons. First, the Manufacturing cost in supply is related to profit directly and thus is an important factor for decision makers to consider. Although the performance of green product innovation is associated with a company's competitive advantage (Chen et al., 2006), companies are fundamentally profit-oriented. There are two factors affecting the strategy of technology innovation, economic performance and environmental performance (Ambec & Lanoie, 2008). The trade-off between economic performance and environmental performance is often considered to be an issue by companies when developing green technologies (Figge & Hahn, 2012), whose main objective is usually profit. As economic performance (profit) is positively related to a company's willingness to invest in green technology, it is likely to have an impact on the decision of green technology innovation. Thus, it needs to be considered when evaluating the influence of incentives on green technology adoption. Moreover, when evaluating the circumstances of green technology innovation, companies' decisions are usually influenced by cost and revenue related factors. For example, the opportunity to increase revenue via selling green technology, and the opportunity to reduce cost via reducing the cost of manufacturing materials or cost of labour can boost company profit (Ambec & Lanoie, 2008) and further enhance green technology innovation. This suggests that the manufacturing cost of green technology development can change the supply's decision making regarding green technology adoption. Second, the empirical evidence obtained in Preliminary Study 2 (*Application of qualitative data 3*) suggests that the supplier's and the manufacturer's main concern of green technology development was the profitability of an investment. As the cost is directly linked to the supply chain's profitability, scenarios where the supply chain experiences a high or low cost of green technology investment have been considered. The influence of this scenario on supply decision making is then analysed in the incentive model.

Scenario 2: The size of the green car market is small

Car companies are more willing to develop green technologies when there is relatively greater market size. This scenario is considered for two reasons. First, extant literature suggests that it is important to consider the size of green market and the ability to differentiate one's own product from that of competitors when making green product marketing strategy (Ginsberg & Bloom, 2004). Second, the empirical data obtained in Preliminary Study 2 (*Application of qualitative data 3*) suggests that the expected green car market size was one of the main concerns of supply chain decision makers when making green technology innovation operational decisions. A rational decision maker tends to invest more if the size of the green car market is large. However, compared to the non-green car market, the size of the green car market is significantly smaller. This can be a barrier to the promotion of green technology through government incentives. Thus, a scenario is considered where the size of a green car market is small, and the supply chain's decision making is studied under this scenario. This scenario also reflects the current situation of the car market in Taiwan. The scenario of big market size is also conducted for comparison with the results of the small market size. In order to understand the effect of market size on the supply chain's decision making, supply chain behaviours in a small and a large green car market have been observed and compared.

VI Parameters setting

In the sensitivity analysis and scenario analysis, parameters' values are obtained using the following technique. First, for supply chain parties, the cost of green technology includes variable cost and fixed costs. Cost related parameters are generated as the percentage of a cost range. The cost range is presented by the maximum and minimum cost collected from the car industry in Taiwan. Cost information is collected through interviews with the manufacturers and suppliers in the car supply chain in Preliminary Study 2. These ranges are standardized so that all the values are defined between zero and one. When the value equals one, the possible cost value reaches its maximal/highest. When the parameter of cost equals zero, the possible cost value reaches its minimal/lowest. The definition of "High" and Low" cost values corresponding to the range are determined by the interviewees for use in the scenario analysis. Second, the green car market size represents the overall market capacity, the bigger the more potential consumers in the market. For the convenience of analysis, the value of market size parameter is taken from zero to one. It is assumed that value one in market size indicates the largest green car market size, whereas the value zero in market size indicates the absence of the green car market. Third, government incentive rates for the supplier and manufacturer are based on the previous incentive projects' data which have been collected in Preliminary Study 2. Because the incentive rate is given as a percentage of the green technology innovation cost, the rate range is set from zero to one. One means all costs are funded/covered by the government (100%), whereas zero means no green technology innovation cost is covered by the government (0%). The definitions of "High" and "Low" incentive rates have been derived from the relevant interview data on previously completed green technology incentive projects in Preliminary Study 2.

VII Simulation process

Assuming supply chain parties make decisions based on the conditions of the current period. Their objectives are profit maximisation, meaning that the technology and pricing decisions are made to achieve the maximum estimated profit. The government monitors project performance to ensure the incentive is used effectively. The supply chain green technology level is the key index for monitoring project progress, the supply chain technology levels are reviewed periodically, and within each period the following sequence of events occurs:

- First step: Incentive rate announcing

The government provides the incentive rates to supply chain (supplier and manufacturer) as the initial incentive rate in period 0.

Government's incentive given to the supplier, parameter setting [0, 1]

Government's incentive given to the manufacturer, parameter setting [0, 1]

- Second step: Market response

A price and green technology level based linear demand function is established as the market response, $Demand = a - bp + c\left(\alpha T_s + \beta T_m\right)$. Uncertainty on market demand is demonstrated by the random values of consumers' sensitivities of price "*b*" and product greenness "*c*" which are obtained from the distributions.

- Third step: Supply chain decision making

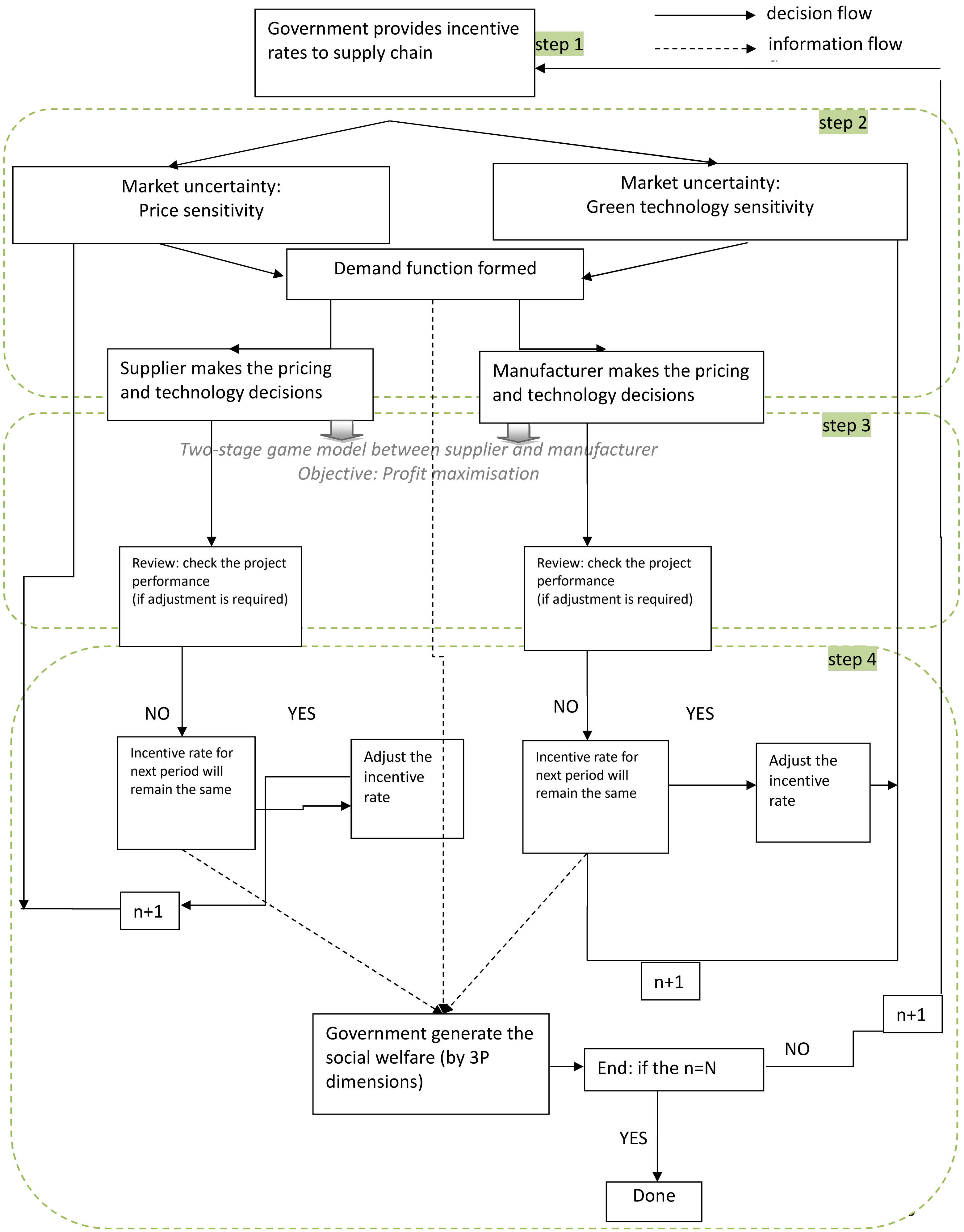
Supplier and manufacturer behavioir are based on a two-stage game model. Pricing and technology decisions are made with the consideration of government incentives, market demand, and relevant costs. An optimisation model is conducted to provide the supplier’s and the manufacturer’s optimal technology and pricing decisions.

- Fourth step: Government reviews the green technology improvement and adjusts the incentive rate for the next period accordingly

Government incentive rate adjustment based on the output of step 3. According to the interview in Preliminary Study 2, government incentive rate is adjustable in each period. The incentive rate is altered for the period after the green technology adoption review. The simulation starts again after this step.

VIII Decision Making Framework

The model starts with the government providing incentives to the supply chain. The supplier and the manufacturer will be informed of the initial incentive rates for green technology adoption. The supply chain then determines the pricing and technology decisions based on the relevant costs (variable and fixed technology investment costs) and the offered incentives. On the market side, the greenness dependent demand is demonstrated, which is led by the price and greenness of the product. Consumers’ green technology sensitivity and price sensitivity changes over the periods, which indicates the uncertainties of the market. Incentive rates also vary in response to the green technology level (evaluation) in the supply chain. Finally, the government adjusts the incentive policy at the end of each period according to the green technology levels and its evaluation of the supply chain. Stopping criteria are also implemented at the end of the model. The total number of rounds is given at the beginning to match the practice. The simulation process ends at period N (when incentive runs out), obtaining the mean of the value of decision variables. Examine the mean and standard deviation, ensuring reasonable differences appear between simulation runs.


decision flow
information flow
Government provides incentive rates to supply chain
step 1
step 2
Market uncertainty: Price sensitivity
Market uncertainty: Green technology sensitivity
Demand function formed
Supplier makes the pricing and technology decisions
Manufacturer makes the pricing and technology decisions
step 3
Two-stage game model between supplier and manufacturer
Objective: Profit maximisation
Review: check the project performance (if adjustment is required)
Review: check the project performance (if adjustment is required)
step 4
NO
YES
NO
YES
Incentive rate for next period will remain the same
Adjust the incentive rate
Incentive rate for next period will remain the same
Adjust the incentive rate
n+1
n+1
n+1
Government generate the social welfare (by 3P dimensions)
End: if the n=N
NO
YES
Done

IX Input and output

Input	Parameter	Output	Parameter
• Government initial incentive rates for supply chain parties	$G_{t=0}$	• Wholesale price	w
		• Product market price	p
• Manufacturer's marginal variable green technology cost	C_m	• Supplier's green technology level	T_{s_t}
• The factor of green technology level change of total fixed green technology cost for manufacturer	C_d	• Manufacturer's green technology level	T_{m_t}
		• Product Greenness	$\alpha * T_{s_t} + \beta * T_{m_t}$
		• Market demand	Q
• Supplier's marginal variable green technology cost	C_s	• Total emission produced	E_{m_t}
		• Consumer benefit from government incentives to supply chain	B_c
• The factor of green technology level change of total fixed green technology cost for supplier	C_f	• Supply chain's profit including supplier and manufacturer	π_{s_t} π_{m_t}

• Market size	a	• Government technology review	R_{s_t} R_{m_t}
		• Incentive rates for each period for SC	G_{s_t} G_{m_t}
• Consumer's price sensitivity on demand	b		
• Consumer's greenness sensitivity on demand	c		
• The weight of the supplier's green technology level impact on final product greenness	α		
• The weight of the manufacturer's green technology level impact on final product greenness	β		

Input variables

- Government initial incentive rates for supply chain parties

    It is the percentage of investment cost covered by the government in the supply chain, there are two input incentive variables:

    $G_{s_{t=0}}$: Initial incentive rate for the supplier

$G_{m_{t=0}}$: Initial incentive rate for the manufacturer

$G_{s_{t=0}}$ = [0,1], $G_{m_{t=0}}$ = [0,1]

- The manufacturer's marginal variable green technology cost

  C_m = [0, 1]

- The factor of green technology level change of the total fixed green technology cost for the manufacturer

  C_d = [0, 1]

- The supplier's marginal variable green technology cost

  C_s = [0, 1]

- The factor of green technology level change of the total fixed green technology cost for the supplier

  C_f = [0, 1]

- Market size

  a = [0, 1]

- The weights of the supplier's and manufacturer' green technology level impact on final product greenness

  α = [0, 1]

  β = [0, 1]

  $\alpha + \beta = 1$

Output variables

- Wholesale price

  Wholesale price is revealed by the optimal solution from the game model between the supplier and manufacturer as the supplier's decision variable. See Appendix 7 for the w*.

- Product market price

  Market price is revealed by the optimal solution from the game model between the supplier and manufacturer as the manufacturer's decision variable. See Appendix 7 for the p*.

- Supplier's green technology level

  T_{s_t} : The green technology level of the supplier in period t

  The supplier's green technology level is revealed by the optimal solution from the game model between supplier and manufacturer as supplier's decision variable. See Appendix for $T_{s_t}{}^*$.

- Manufacturer's green technology level

  T_{m_t} : The green technology level of the manufacturer in period t

  The manufacturer's green technology level is revealed by the optimal solution from the game model between the supplier and manufacturer as the manufacturer's decision variable. See Appendix for $T_{m_t}{}^*$

- Product Greenness

  Product Greenness is the aggregation of the supplier's and manufacturer's green technology levels, it is formulated as $\alpha * T_{s_t} + \beta * T_{m_t}$.

- Market demand

  $$Q = a - bp \ + c\left(\alpha T_s + \beta T_m\right)$$

- Consumer benefit from government incentives for the supply chain

  The change of green technology level: $c\left(\alpha T_{s_t} + \beta T_{m_t}\right) - c\left(\alpha T_{s_{t-1}} + \beta T_{m_{t-1}}\right)$

  The change of the price: $p_t - p_{t-1}$

  $$B_c = [c\left(\alpha T_{s_t} + \beta T_{m_t}\right) - c\left(\alpha T_{s_{t-1}} + \beta T_{m_{t-1}}\right)] + (p_t - p_{t-1})$$

- Supply chain profit

  $$\pi_{s_t}\left(w_t, T_{s_t}\right) = \left(w_t - T_{s_t} C_s (1 - G_{s_t})\right)\left(a - bp_t + c\left(\alpha T_{s_t} + \beta T_{m_t}\right)\right) - (T_{s_t} - T_{s_{t-1}})^2 C_f (1 - G_{s_t})$$

  $$\pi_{m_t}\left(p_t, T_{m_t}\right) = \left(p_t - w_t + T_{m_t} C_m (1 - G_{m_t})\right)\left(a - bp_t + c\left(\alpha T_{s_t} + \beta T_{m_t}\right)\right) - (T_{m_t} - T_{m_{t-1}})^2 C_d * (1 - G_{m_t})$$

- Technology review in the supply chain

  Rs_t : The green technology review for the supplier at period t

  Rm_t : The green technology review for the manufacturer at period t

  Green technology level dependent review for the supplier:

  $Rs_t = \varepsilon_s * (Ts_t - Ts_{t-1})$

  Green technology level dependent review for the manufacturer:

  $Rm_t = \varepsilon_m * (Tm_t - Tm_{t-1})$

- Incentive rates with adjustment for each period for supply chain

  The incentive rate at period t for the supplier:

  $Gs_t = Gs_{t-1} + Rs_{t-1}$

  The incentive rate at time t for the manufacturer:

  $Gm_t = Gm_{t-1} + Rm_{t-1}$

6.3 Result

6.3.1 Introduction

In order to increase the efficiency of government incentives to drive green technology development and adoption in the supply chain, it is important to understand the implementation of government incentives and the corresponding decision making. Although this issue has been examined before, previous studies have taken the perspective of the government, and thus are limited in providing an understanding of the issue from the perspective of supply chain management. In an attempt to address this research deficit, this study aims to gauge the influence of government incentives on green technology development and adoption in the automobile industry from the perspective of supply chain management, and illustrate the optimal decision making for the supply chain management. This section presents the analysis of the stochastic simulation model. The design of the experiment is based on the research questions.

I The structure of the section

The analysis is organised in accordance with the sequence of the research questions. Firstly, section 6.3.1 presents the introduction of the result section. In order to answer the main research question, "*How do government incentives affect supply chain behaviours*?", two sub questions have been asked. The results of the analysis are presented accordingly. It is worth noting that the supplier and the manufacturer are the two main decision makers in the supply chain, and thus the decision making of these two parties is examined separately. Results concerning sub research question 1, "*How do government green incentives affect supply chain's green technology decision making*?", are presented in section 6.3.2. Under this section, the influence of government incentives on the supplier's decision making regarding green technology adoption is demonstrated in section Part 1, whereas similar results on the manufacture's green technology decision making are presented in section Part 2. Results concerning the sub research question 2, "*How does the government's green incentive affect supply chain's pricing*?", are presented in section 6.3.3. Under this section, the influence of government incentives on the supplier's pricing decision is demonstrated in section Part 1, and similar results regarding the manufacture's pricing decision are presented in section Part 2. Finally, section 6.3.4 is the conclusions that summarises the research findings.

6.3.2 Sub research question 1

This section aims to address sub research question 1: "*How does the government's green incentive affect supply chain's green technology decision making?*", by illustrating the influence of government incentives on supply chain decisions regarding green technology development and adoption.

The aim of this research is the supply chain behaviour change given the government incentives. As government provides incentives separately to the supplier and the manufacturer, their behaviour (decision making) is expected to be observed separately. To consider the sum of the supplier and manufacturer weighted green technology level, the factors setting of the weights will be involved in the analysis which affects the focus of a supply chain party's green technology level. Thus, the influences of incentive on the change of green technology levels of the supplier and the manufacturer are presented separately in the result section, including Part 1: Implication to the supplier's green technology decision making and Part 2: Implications of the manufacturer's green technology decision making

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Part 1: Implications to the supplier's green technology decision making

The relationship between the government incentive rate and the supplier's green technology level is illustrated in this section in order to demonstrate the impact of government incentives on the supplier's decision making regarding its green technology development and adoption. The following figures present the *mean value* of 150 runs of simulation for 50 periods. The variances are between 2% to 10% of the mean values in all periods.

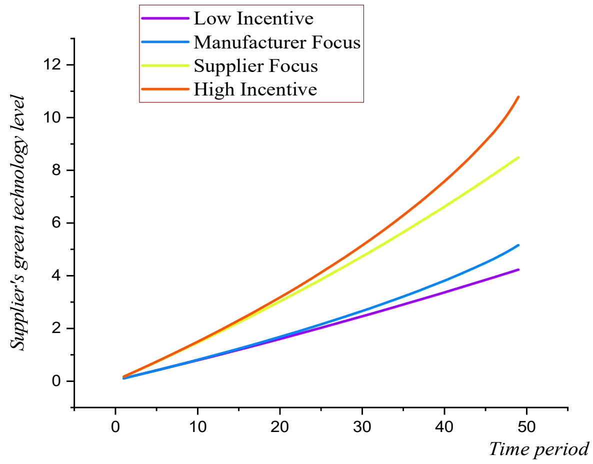

Figure 32- The influence of government incentives on the supplier's green technology level when the cost of green technology innovation is low

*Input parameter values: $a = 0.5$, $C_s = 0.1$, $C_{ts} = 0.2$, $C_{tm} = 0.1$, $C_m = 0.25$, $\alpha = 0.4$, $\beta = 0.6$

The results suggest that the most efficient incentive strategy to enhance the supplier's green technology level is to provide both the supplier and the manufacturer with high government incentive rates. The relationship between the government incentive rate and the supplier's green technology level is more significant when the supplier is given a high incentive rate. The slope of the supplier's green technology level over time is smaller when the supplier is given a low incentive rate.

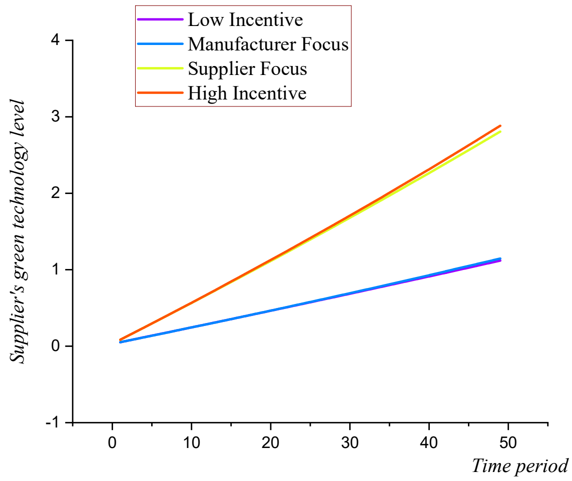

Figure 33 - The influence of government incentives on the supplier's green technology level when the cost of green technology innovation is high

*Input parameter values: $a = 0.5, C_s = 0.2, C_{ts} = 0.4, C_{tm} = 0.2, C_m = 0.5, \alpha = 0.4, \beta = 0.6$

Figure 33 shows that different incentive strategies can possibly have a similar effect on the supplier's green technology level. "High incentive" and "Supplier focus" strategies result in the same improvement to the supplier's green technology level. "Low incentive" and "Manufacturer focus" strategies lead to less positive influence on green technology innovation by incentives. In general, the supplier is likely to make a decision to improve its green technology level if a high incentive rate is provided to the supplier itself.

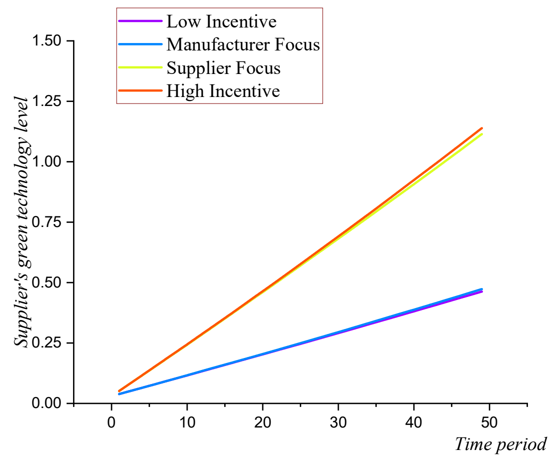

Figure 34 - The influence of government incentives on the supplier's green technology level when the size of the green car market is small

*Input parameter values: $a = 0.2,\ C_s = 0.2,\ C_{ts} = 0.4,\ C_{tm} = 0.2,\ C_m = 0.5,\ \alpha = 0.4,\ \beta = 0.6$

Four combinations of government incentive strategies have been employed in this project, and they all show a positive influence on the supplier's green technology level. It is found that the supplier has better green technology improvement of the incentive project when it is given a high rather than low incentive rate.

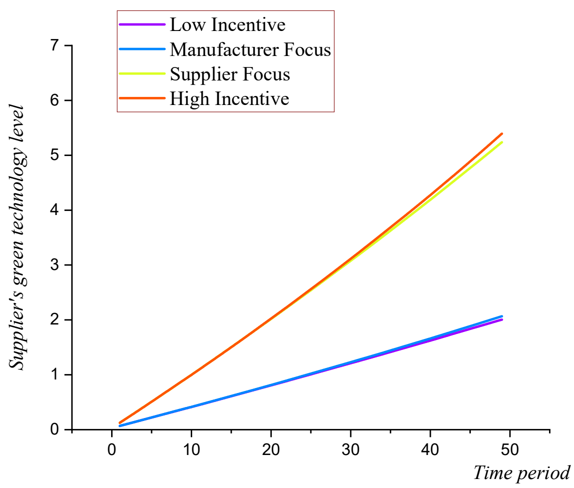

Figure 35 - The influence of government incentives on the supplier's green technology level when the size of the green car market is big

*Input parameter values: $a = 0.9$, $C_s = 0.2$, $C_{ts} = 0.4$, $C_{tm} = 0.2$, $C_m = 0.5$, $\alpha = 0.4$, $\beta = 0.6$

Figure 34 and Figure 35 suggest that there is no significant difference between the small market size and big market size regarding the selection of incentive strategies. In general, bigger market size leads to more improvement in the supplier's green technology level over time.

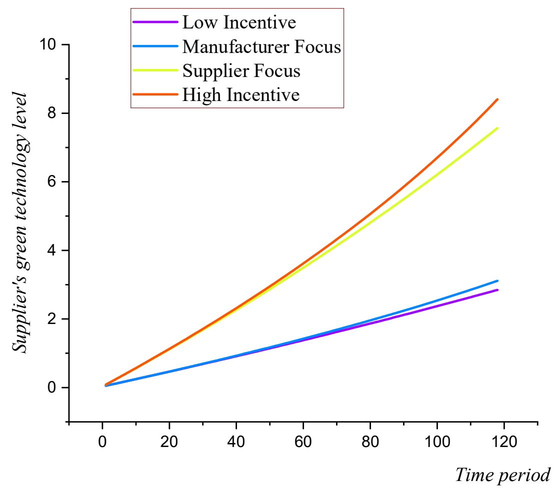

Figure 36 - The impact of government incentives on the supplier's green technology level in a long-term view

*Input parameter values: $a = 0.5$, $C_s = 0.2$, $C_{ts} = 0.4$, $C_{tm} = 0.2$, $C_m = 0.5$, $\alpha = 0.4$, $\beta = 0.6$

Figure 36 shows that from the long-term viewpoint, the High Incentive strategy is the best one to conduct for supplier's green technology innovation. Supplier Focus strategy is the second-best, and it is followed by Manufacturer Focus strategy.

Findings of the supplier's green technology decision

To improve the supplier's green technology level to its best, High Incentive strategy should be employed when the green technology cost is low (Figure 32). The second-best strategy is Supplier Focus, and this is followed by Manufacturer Focus strategy. This indicates that the supplier's green technology level can be enhanced to its highest when both the supplier and the manufacturer receive high incentive rates. A supplier in Preliminary Study 2 illustrates this: "*We are sometimes asked by the manufacturer to customize a part used in green cars manufacturing when the downstream participates in a government green technology funded project*". The supplier can be motivated by either the government or the manufacturer to improve the green technology level. When the government and the manufacturer encourage/motivate the supplier simultaneously (High incentive strategy), the supplier has the strongest will to invest in green technology innovation. However, when the green technology innovation cost is high, no significant difference appears between High Incentive strategy and Supplier Focus strategy (Figure 33). This implies that whether the manufacturer is receiving the high incentive rate does not affect the supplier's green technology improvement when the supplier's green technology costs are high. As the upper tier in the supply chain, the supplier's green technology decision is more independent from the manufacturer when the investment cost is high. However, when the cost of green technology innovation is low, the supplier must consider the manufacturer's incentive rate. In this case, the incentive rate of the manufacturer does not only affect its own green technology improvement, but also the supplier's green technology decision. Only when the supplier and the manufacturer work together (both supported by government's high-rate incentives at the same time), can the supplier overcome the difficulty of high cost and invest more in green technology.

Proposition 1: *The supplier's green technology decision is influenced by both the supplier's and manufacturer's incentives, however, it is only influenced by the manufacturer's incentives when both the supplier's and the manufacturer's cost of green technology innovation are low.*

Although the market size is important for supply chain's marketing strategy concerning green products (Ginsberg & Bloom, 2004), for the objective of improving the supplier's green technology, the government's selection of incentive strategy is not affected by the market size (Figure 34 and Figure 35). For the supplier, High Incentive strategy and Supplier Focus strategy are the best in terms of maximising the supplier's green technology level. These two strategies have similar effects: Manufacturer Focus strategy and Low Incentive strategy have resulted in a similar green technology improvement of the supplier. The best government incentive strategy is dependent on the presence of the supplier's high incentive rate. Because the supplier is at the upper stream of the supply chain and does not face the market directly, the influence of market size shows no significant impact on the selection of incentive strategies in regard to the supplier's green technology improvement.

Proposition 2: *The size of the green car market has a positive effect on the supplier's green technology improvement driven by the incentives, whereas it does not have a significant influence on the selection of government incentive strategies in terms of the supplier's green technology improvement.*

Observed long-term, the differences between the four strategies of the supplier's green technology innovation become apparent (Figure 36). With a short-term project, the positive effect on the supplier's green technology innovation of the High Incentive strategy and the Supplier Focus strategy is close, but the High Incentive strategy is recognized as a better strategy for a long-term incentive project.

Part 2: Implications of the manufacturer's green technology decision making

The relationship between government incentive rates and the manufacturer's green technology level is illustrated in this section in order to demonstrate the ways in which government incentives affect the manufacturer's decision making regarding its green technology development and adoption. The following figures present the *mean value* of 150 runs of simulation for 50 periods. The variances are between 2% to 10% of the mean values in all periods.

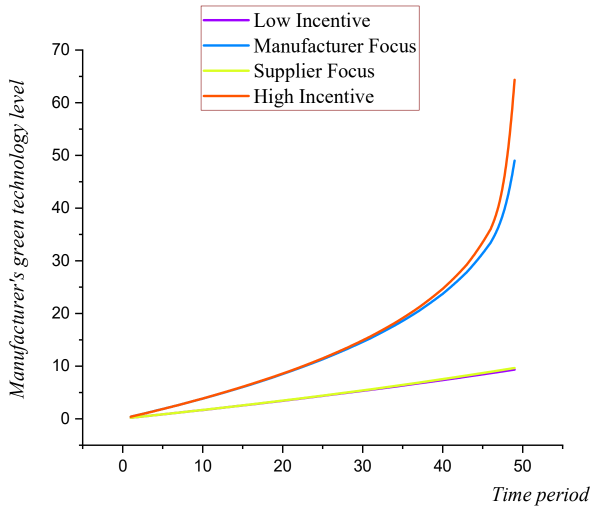

Figure 37 - The influence of government incentives on the manufacturer's green technology level when the cost of green technology innovation is low

*Input parameter values: $a = 0.5$, $C_s = 0.1$, $C_{ts} = 0.2$, $C_{tm} = 0.1$, $C_m = 0.25$, $\alpha = 0.4$, $\beta = 0.6$

In general, the government's incentive rate for the manufacturer increases over the periods. As this incentive rate increases, its effect on the manufacturer's green technology level becomes more significant. Government incentives demonstrate a consistently positive effect on the manufacturer's green technology level.

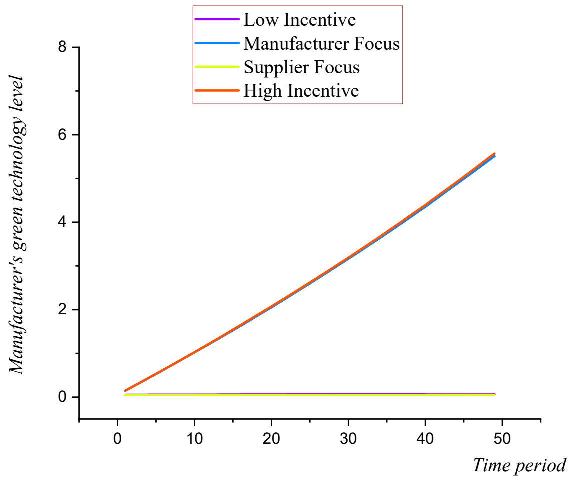

Figure 38 - The influence of government incentives on the manufacturer's green technology level when the cost of green technology innovation is high

*Input parameter values: $a = 0.5$, $C_s = 0.2$, $C_{ts} = 0.4$, $C_{tm} = 0.2$, $C_m = 0.5$, $\alpha = 0.4$, $\beta = 0.6$

When the manufacturer is given a low government incentive rate, the manufacturer's green technology level fails to show any significant improvement over time. However, when the manufacturer receives a high government incentive rate, its green technology level increases along with time.

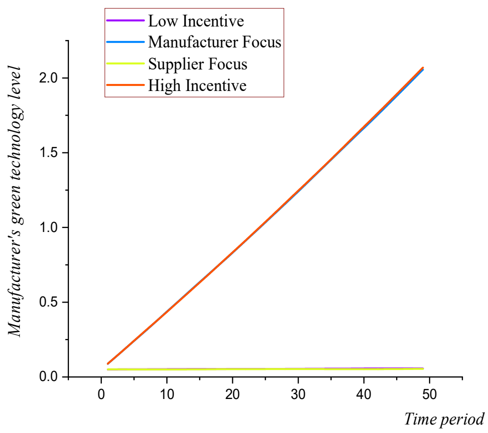

Figure 39 - The influence of government incentives on the manufacturer's green technology level when the size of the green car market is small

*Input parameter values: $a = 0.2, C_s = 0.2, C_{ts} = 0.4, C_{tm} = 0.2, C_m = 0.5, \alpha = 0.4, \beta = 0.6$

It can be observed in Figure 39 that the manufacturer's green technology level increases overtime only if the government offers a higher incentive rate than the supplier to the manufacturer. The incentive strategy of "High incentives" and "Manufacturer focus" both provide the manufacturer with a high incentive rate, and it is found that the manufacturer improves its green technology as long as its incentive rate is high. This is regardless of the government incentive rate received by the supplier.

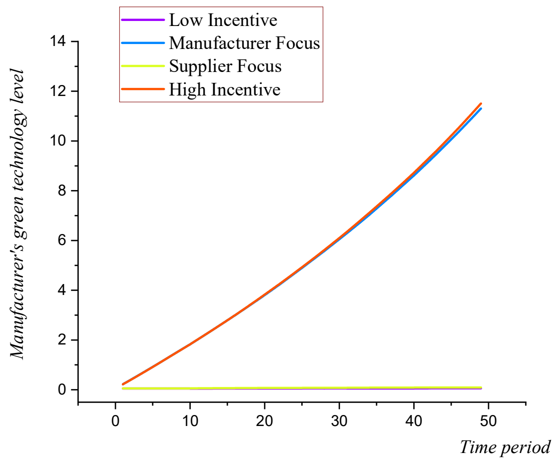

Figure 40 - The influence of government incentives on the manufacturer's green technology level when the size of the green car market is big

*Input parameter values: $a = 0.9, C_s = 0.2, C_{ts} = 0.4, C_{tm} = 0.2, C_m = 0.5, \alpha = 0.4, \beta = 0.6$

The results suggest that the manufacturer improves its green technology over the periods only if it is provided with a high incentive rate. Compared to the results in Figure 39, the manufacturer's green technology level tends to be higher in general, when the market size is bigger. In other words, the green technology investment of the manufacturer is less likely to be driven by the government incentives when the incentive rate is relatively low.

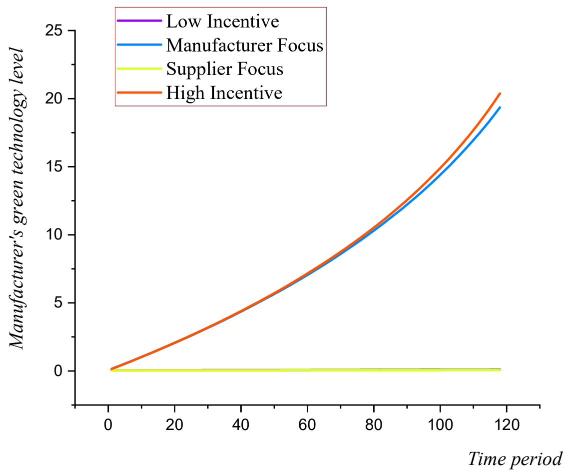

Figure 41 - The impact of government incentives on the manufacturer's green technology level in a long-term view

*Input parameter values: $a = 0.5, C_s = 0.2, C_{ts} = 0.4, C_{tm} = 0.2, C_m = 0.5, \alpha = 0.4, \beta = 0.6$

Figure 41 indicates that, from a long-term viewpoint, the High Incentive strategy is the best one to conduct for the manufacturer's green technology innovation. The second-best is the Manufacturer Focus strategy. Even given long-term incentives, both Supplier Focus strategy and Low Incentive strategy only present a minimal positive impact on the manufacturer's green technology innovation.

Findings of the manufacturer's green technology decision

To increase the manufacturer's green technology level, High Incentive strategy and Manufacturer Focus incentive strategy should be employed (Figure 37) when the manufacturing cost is low. It is found that all four incentive strategies can help to increase the manufacturer's green technology level when the cost is low. The improvement resulted from Low Incentive strategy and Supplier Focus strategy is less than that from High Incentive strategy and Manufacturer Focus strategy. When the manufacturer makes its green technology decision, a trade-off between the increase of cost and the increase of green technology appears. Given the low cost of green technology investment, the manufacturer is less concerned of cost. Hence, the financial obstacle of green technology investment is reduced. In the case of the high cost of green technology, a manufacturer suggested in an interview that "*Our main problem for green car design and manufacturing is the money (cost), even with the support of the government's project we still cannot ensure that it is profitable to invest in green technology development*." When manufacturing cost is high, the improvement in green technology is less than that in the scenario of low manufacturing cost (Figure 37 and Figure 38). This indicates that the manufacturer's willingness to invest is higher when the cost is low, and the manufacturer tends to be more reserved when the cost is high. To achieve the best improvement in the manufacturer's green technology, either High Incentive strategy or Manufacturer Focus strategy should be employed. When the cost is high, both the Low Incentive strategy and Supplier Focus strategy have only minimal positive impact on green technology improvement. Thus, when the aim is to improve the manufacturer's green technology, the government should allocate more incentives to the manufacturer instead of balancing the incentive allocation between the supplier and the manufacturer.

Proposition 3: *The manufacturer increases its green technology level over time in response to the incentives. Providing high incentive rate to the manufacturer is needed in order to drive the manufacturer's green technology improvement when the cost of green technology innovation is high.*

It is found that the manufacturer's green technology improvement is more significant when the size of the green car market is large (Figure 39 and Figure 40). One of the main issues in green product development is the size of the green car market. A quotation from an interview in Study 2 notes that "*It is a fact that the green car market is still very small compared to the non-green car market, most of we manufacture are still for the non-green car market*". This suggests that the manufacturer is more willing to invest in green technology when the size of the green car market is large enough to significantly increase expected car sales. In a green car market of a large size, the High Incentive strategy proves to be the best strategy. The second-best strategy is the Manufacturer Focus strategy, which brings slightly less green technology improvement than the High Incentive strategy. This is due to the manufacturer expecting the supplier to collaborate on green technology improvement, and this requires a high incentive rate not only to the manufacturer but also the supplier. When the size of the green car market is small, both High Incentive strategy and Manufacturer strategy have similar positive impacts on the manufacturer's green technology improvement (Figure 39 and Figure 40). Under this circumstance, the supplier's incentive rate only has a minimal effect on the manufacturer's green technology decision. Overall, the influence of the green car market's size on the government's incentive strategy selection in terms of the manufacturer's green technology improvement is not significant. Notably, the impact of incentives on the manufacturer's green technology for a long-term project is consistent with a short-term project (Figure 41). Thus, the government is suggested to use the same strategy for both short-term and long-term incentive projects for managing the manufacturer's green technology improvement.

Proposition 4: *The size of the green car market has a positive effect on the manufacturer's green technology improvement driven by the incentives, whereas it does not have a significant influence on the selection of government incentive strategies in terms of the manufacturer's green technology improvement.*

6.3.3 Sub research question 2

This section aims to address sub research question 2, "*How do government green incentives affect the supply chain's pricing strategy?*", by illustrating the influence of government incentives on supply chain decisions regarding pricing. The influences on the pricing decisions of the supplier and the manufacturer and the corresponding findings are demonstrated in section Part 1 and Part 2 respectively.

Part 1: Implications to the supplier's pricing decision

The relationship between the government incentive rate and the supplier's pricing decision is illustrated in this section in order to demonstrate the effect of government incentives on the supplier's decision-making regarding pricing. The following figures present the *mean value* of 150 runs of simulation for 50 periods. The variances are between 2% to 10% of the mean values in all periods.

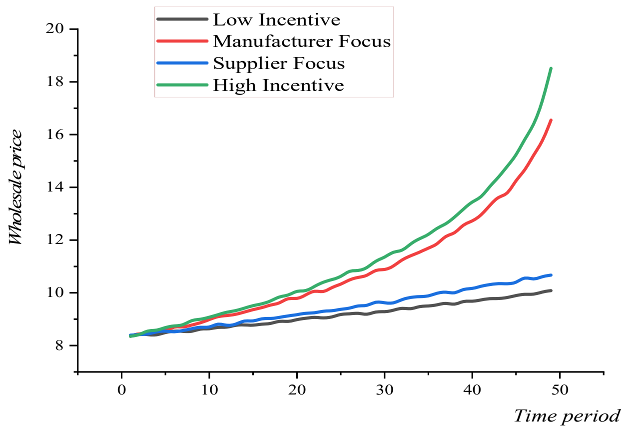

Figure 42 - The influence of government incentives on the supplier's wholesale price when the cost of technology innovation is low

*Input parameter values: $a = 0.5, C_s = 0.1, C_{ts} = 0.2, C_{tm} = 0.1, C_m = 0.25, \alpha = 0.4, \beta = 0.6$

The results suggest that the supplier's wholesale price changes gradually over time when the supplier receives a high government incentive rate. The supplier's wholesale price has limited changes if the supplier is given a low government incentive rate.

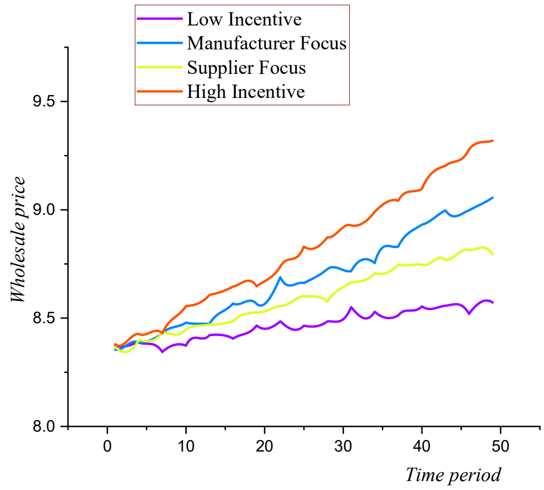

Figure 43 - The influence of government incentives on the supplier's wholesale price when the cost of technology innovation is high

*Input parameter values: $a = 0.5,\ C_s = 0.2,\ C_{ts} = 0.4,\ C_{tm} = 0.2,\ C_m = 0.5,\ \alpha = 0.4,\ \beta = 0.6$

Figure 43 shows that the supplier's wholesale price goes up over time. It also reflects the cost of the supplier's green technology improvement as the level of green technology increases over time. "High incentive" strategy proves to be most effective on the supplier's wholesale price as it provides both the supplier and the manufacturer with high government incentive rates. When the government provides low incentive rates to the supply chain, a limited change in the wholesale price is observed. Notably, the government incentive rate for the manufacturer, in comparison to that for the supplier, has a more significant effect on the supplier's wholesale price.

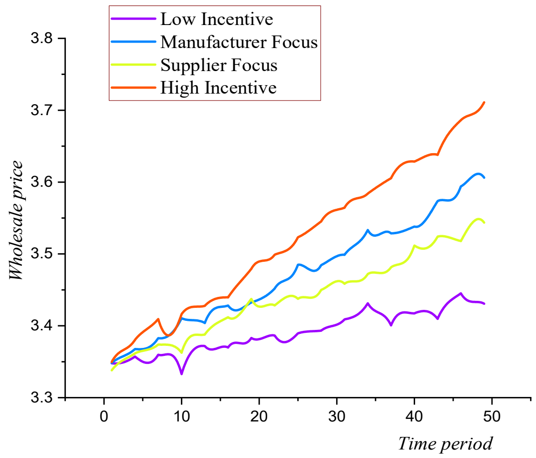

Figure 44 - The influence of government incentives on the supplier's wholesale price when the size of the green car market is small

*Input parameter values: $a = 0.2,\ C_s = 0.2,\ C_{ts} = 0.4,\ C_{tm} = 0.2,\ C_m = 0.5,\ \alpha = 0.4,\ \beta = 0.6$

The curves in Figure 44 indicate that the government incentive rate is positively related to the supplier's wholesale price. Because the green technology level in the supply chain increases over time (Figure 34), the increase of the supplier's wholesale price actually reflects the green technology innovation cost. Hence, the price goes up when the government incentive rate for either the supplier or the manufacturer increases, to reflect the cost of green technology investment.

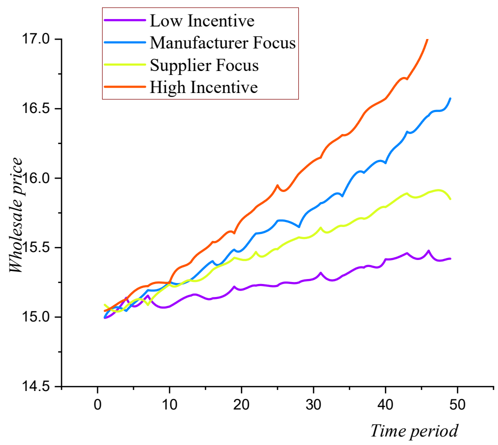

Figure 45 - The influence of government incentives on the supplier's wholesale

price when the size of the green car market is big

*Input parameter values: $a = 0.9$, $C_s = 0.2$, $C_{ts} = 0.4$, $C_{tm} = 0.2$, $C_m = 0.5$, $\alpha = 0.4$, $\beta = 0.6$

Having compared Figure 44 and Figure 45, it was found that the market size has no significant effect on the selection of government incentive strategies. The supplier's wholesale price is influenced by the government incentive rate for both the supplier and the manufacturer. Moreover, the government incentive rate for the manufacturer, in comparison to that for the supplier, has a more positive effect on the supplier's wholesale price.

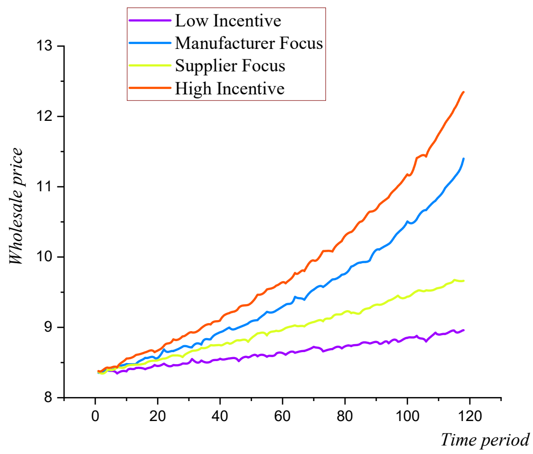

Figure 46 -The influence of government incentives on the supplier's pricing decision from a long-term perspective

*Input parameter values: $a = 0.5$, $C_s = 0.2$, $C_{ts} = 0.4$, $C_{tm} = 0.2$, $C_m = 0.5$, $\alpha = 0.4$, $\beta = 0.6$

Long-tern, it can be observed that the High Incentive strategy leads to the highest wholesale price, and Low Incentive strategy leads to the lowest wholesale price. The Manufacturer Focus strategy and Supplier Focus strategy show a medium wholesale price. Wholesale price increases over the period in all strategies.

Findings of the supplier's pricing decision

The wholesale price goes up as the supplier's green technology level increases. When green technology costs are low, the High Incentive strategy leads to the highest wholesale price (Figure 42). This is because when the supplier's green technology level is high, the supplier tends to increase the wholesale price to reflect the cost of green technology investment. Looking at the green technology improvement in Figure 32 where the Supplier Focus strategy performs better than the Manufacturer Focus one, it is found that the Supplier Focus strategy corresponds to a lower wholesale price than the Manufacturer Focus strategy. This is due to the supplier only receiving low incentive rates in the Manufacturer Focus strategy, and thus the green technology cost results in the increase of the wholesale price. Although the Supplier Focus strategy leads to more improvement in the supplier's green technology, the supplier tends not to significantly increase the wholesale price. This is because that part of the cost is already covered by the government through a high incentive rate. In the case of a high manufacturing cost, comparing Figure 33 and Figure 43 it has been found that the wholesale price moves along with the green technology improvement in all incentive strategies. The High Incentive strategy shows the highest wholesale price because this strategy leads to the highest green technology level. When the green technology costs are high, the difference in pricing decisions between any two strategies is more significant than when the costs are low. That is, a pricing decision is more sensitive to the green technology level resulted from high costs. The wholesale price is less sensitive to the green technology level when the costs of green technology are low.

Proposition 5: *When the cost of green technology is high, the supplier offers a higher price to the manufacturer, and at the same time, the supplier's pricing decision is more sensitive to the provided incentive strategy.*

Overall, the wholesale price is higher when the size of the green car market is larger (Figure 44 and Figure 45). Having observed the supplier's green technology level and the wholesale price jointly (Figure 34, Figure 35, Figure 44 and Figure 45), it has been found that the wholesale price does not necessarily follow the supplier's green technology level. In addition, there is no significant difference of incentive strategy selection between short-term and long-term incentive projects. Although both the High Incentive strategy and the Supplier Focus incentive strategy lead to a high level of improvement in the supplier's green technology, the wholesale price is lower in the Supplier Focus strategy than that in the High Incentive strategy. This is due to the manufacturer receiving only low incentive rates in the Supplier Focus strategy, and thus its willingness to invest in green technology remains relatively low. As a result, the optimal wholesale price to offer to the manufacturer should be low enough to reflect its green technology level. This can ensure that the manufacturer sets a reasonable product price to secure the market demand since the demand is price sensitive (Abad, 1994).

Proposition 6: *There is a positive relationship between the size of the green car market and the pricing decision of the supplier. When the size of the green car market is big, the manufacturer does not respond to different incentive strategies sensitively.*

Part 2: Implications to the manufacturer's pricing decision

The relationship between government incentive rates and the manufacturer's pricing decision is illustrated in this section in order to demonstrate the effect of government incentives on the manufacturer's decision-making regarding pricing. The following figures present the *mean value* of 150 runs of simulation for 50 periods. The variances are between 2% to 10% of the mean values in all periods.

Cost of technology innovation

Under the scenario of the low cost of technology innovation, the result from the manufacturer's perspective is similar to the supplier's perspective. That is, the pricing decision affected by the incentives in both supplier and manufacturer have the same trend. High Incentive strategy and Manufacturer Focus strategy lead to higher wholesale price and higher product price. Supplier Focus strategy and Low Incentive strategy result in lower wholesale and product price.

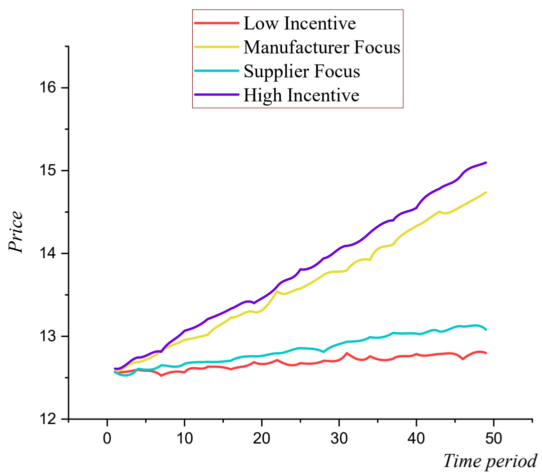

Figure 47 - The influence of government incentives on the manufacturer's product price when the cost of technology innovation is high

*Input parameter values: $a = 0.5, C_s = 0.2, C_{ts} = 0.4, C_{tm} = 0.2, C_m = 0.5, \alpha = 0.4, \beta = 0.6$

The results suggest that the influence of government incentives on product price becomes more significant when the manufacturer is given a high incentive rate. In terms of the manufacturer's green technology improvement, the government incentive strategies of "High incentive" and "Manufacturer focus" are more efficient than the "Low incentive" and "Supplier focus" ones. That is, the manufacturer improves more when it is given an equal or higher government incentive rate than the supplier.

Market size

To compare the scenarios of small and big market sizes, it was found that a bigger market is generally associated with a higher product price. When the market size is big, the supply chain green technology level tends to be high as well. Hence, the price is affected by the cost of green technology innovation. There is no significant difference in terms of the selection of government incentive strategies between small and big markets.

The influences of four incentive strategies have the same effect on both supplier and manufacturer's pricing strategies. The results suggest that higher incentive rates for both supplier and manufacturer have a more significant effect on the price compared to other incentive strategies. Notably, the increase in government incentives tends to result in the rise of the product price, because green technology increases at the same time. Thus, to reflect the green technology investment, product price rises when the government incentive rate for either the supplier or the manufacturer increases.

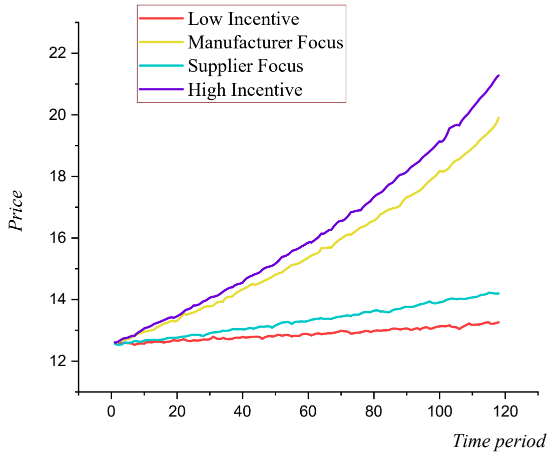

Figure 48 - The influence on the manufacturer's pricing decision from a long-term perspective of government incentive rate for the supplier

*Input parameter values: $a = 0.5$, $C_s = 0.2$, $C_{ts} = 0.4$, $C_{tm} = 0.2$, $C_m = 0.5$, $\alpha = 0.4$, $\beta = 0.6$

Long-term, product price increases over the periods. Both the High Incentive strategy and the Manufacturer Focus strategy cause a significant increase in the price over the time-periods. The product price shows only small changes over time with the Supplier Focus and Low Incentive strategy.

Findings of the manufacturer's pricing decision

It was found that the product price increases as the manufacturer's green technology level increases. When the green technology costs are low, the product price rises along with the manufacturer's green technology level, and this is consistent with the trend of the supplier's wholesale price. A manufacturer stated in an interview that "*The manufacturing cost normally is reflected by the price, because now we still have a problem to cost down the green cars' manufacturing. The marketing team has the cost information and they determine the price according to the company's current marketing strategy*." Thus, the result shows that the product price is more sensitive to the manufacturer's green technology level when the manufacturing cost is high (Figure 47). With Low Incentive strategy and Supplier Focus strategy, product price increases slowly even when the increase of green technology is very small. To conclude, market size does not have a significant influence on the selection of incentive strategies, but the sensitivity of green technology to price is high when the cost of technology innovation is high.

Proposition 7: *The product price does not reflect the increase of green technology innovation cost directly, yet it is highly dependent on the manufacturer's green technology decision. The product price is more sensitive to manufacturer's green technology when the cost of green technology innovation is high.*

Overall, product price is lower in a larger green car market than in a small one. This is because the manufacturer tends to invest more in green technology (high car greenness) in the large green car market. The product price is connected to product greenness, and thus the price goes up over the periods when the green technology level increases. The trend of price increases over time is consistent also for a long-term incentive project (Figure 48). Due to the green technology innovation performing well in the High Incentive strategy and the Manufacturer strategy, it is expected to obtain high product prices from these two strategies. Notably, the product price stays low even if the manufacturer only receives low incentive rate (in Low Incentive strategy and Supplier Focus incentive strategy). This is possibly due to the manufacturer being aware of its own low green technology level and thus keeping its price low in order to maintain a certain level of demand. A manufacturer in an interview mentioned that "*We need to produce green cars with a reasonable price, otherwise the consumer will find it difficult to accept the price difference between green cars and normal cars; normally cars with good greenness degree and low price are most popular*." In the green car market, a balance between price and green technology is necessary in order to ensure product sales. To conclude, it has been found that the manufacturer's pricing decision is affected by its own green technology level, government incentive strategy and the size of green car market. No significant evidence has been discovered to suggest any effect of the green car market size on the selection of incentive strategy.

Proposition 8: *There is a positive relationship between the size of the green car market and the pricing decision of the manufacturer. However, the size of the green car market does not have a significant influence on the selection of government incentive strategy in terms of the manufacturer's pricing decision.*

6.3.4 Conclusion

In summary, both the supplier's and the manufacturer's green technology innovations are influenced by the selection of government incentive strategy. A different incentive strategy is suggested in different market scenarios. Furthermore, the supply chain's pricing decisions are not directly affected by the incentives. The wholesale price and the product price are not reduced by the incentive offered to the supply chain, and they are not significantly affected by the cost of green technology. Instead, pricing decisions follow the trend of green technology innovation closely. Evidence shows that higher green technology level leads to higher total green technology costs, meaning that supply chain pricing reflects indirectly the increase of green technology costs. To conclude, government incentives influence directly the supply chain's green technology decisions, and indirectly the supply chain's pricing decisions.

High Incentive strategy is found to be the most efficient incentive strategy for green technology innovation. However, this strategy is likely to result in a high product price. When there is a priority between the supplier's and the manufacturer's green technologies, this relates to whether the Supplier Focus strategy or the Manufacturer Focus strategy should be employed. Because Manufacturer Focus strategy has the same positive impact as the High Incentive strategy on the manufacturer's green technology improvement, this is proposed for use when the aim is only to improve the manufacturer's green technology. To achieve a high level of green technology at a low price, the Supplier Focus strategy should be employed.

Chapter 7: Discussion and conclusions

7.1 Introduction

To investigate the influence of government incentives on supply chain behaviour from a supply chain management perspective, this research study provides answers to one main research question "*How do government incentives affect supply chain behaviours*?" and two sub research questions: "*How do government green incentives affect supply chain's green technology decision making*?" and "*How does government green incentives affect supply chain's pricing*?" By answering the research questions, this research contributes in supply chain management from an operational research perspective.

In this research, incentive models have been built to illustrate how government incentives affect supply chain behaviour and change supply parties' green technology and pricing decisions. In addition, semi-structured interviews have been conducted with car suppliers and manufacturers in Taiwan. The qualitative data obtained from the semi-structured interviews was used to validate and inform the model. The results confirmed the influence of government incentives on the supply chain's decision making. Both the green technology decision and pricing decision in the supply chain are affected by government incentives. Generally, in short term observation, the green technology levels of supplier and manufacturer increase following the rise of incentive rates by the government. However, the impacts of incentives are various under different scenarios of the market environment, which is high or low investment costs in supply chain and big or small green car market size. In the long-term, government incentives tend to have positive effects on green technology improvements in the supply chain. In order to achieve optimal decision-making for profit maximisation, supply chain parties ought to consider the incentive circumstances of their upstream and downstream at the same time. Based on the analytical results of the model, this research study proposes four incentive strategies in response to different market scenarios for the government's green policy making. High incentive strategy leads to the best green technology improvement in the supply chain. When the government has a limited budget of green incentives, the use of Manufacturer Focus strategy or Supplier Focus strategy is considered.

To achieve the manufacturer's green technology improvement by providing government incentives, High Incentive strategy and Manufacturer Focus strategy are more efficient than Supplier Focus and Low Incentive strategies. This study found that the manufacturer's green technology level increases more when the manufacturer receives higher incentive rates than the supplier. The manufacturer's green technology has only limited improvement when the supplier receives higher incentive rates than the manufacturer especially when green technology innovation costs are high. It was also found, however, that the manufacturer is willing to invest more in green technology with a bigger green car market. The selection of the government's green policy strategy is not significantly affected by the green market size.

To achieve the supplier's green technology improvement by providing government incentives, High Incentive strategy and Supplier Focus incentive strategy are more efficient than Low Incentive strategy and Manufacturer Focus incentive strategy. When the green technology innovation costs are reasonably low, whether the manufacturer's incentive rate is as high as the supplier's incentive rate or not, has an impact on green technology decisions. That is, High Incentive strategy performs better than Supplier Focus incentive strategy in terms of the green technology improvement. However, when the green technology costs in the supply chain are high, there is no difference between

High Incentive strategy and Supplier Focus strategy. This enquiry has also found that green market size does not influence on the selection of the government's green policy strategy.

This project concludes that the pricing strategy in the supply chain is also affected by the government green incentives. Notably, higher incentive rates in the supply chain lead to higher wholesale and final product prices because green incentives enhance green technology so that the marginal green technology cost increases. Thus, the increase of the pricing decisions is due to the high production costs. Government incentives do not lower the price offered to the market but increase product greenness.

Having answered the main research question of the influence of government incentive on supply chain behaviour, the sub research questions of the influence of government incentives on green technology decisions and the influence of government incentives on pricing decision, this study does not only make significant contributions to the literature but also provides managerial implications to practitioners in the field of supply chain management and public policy management. These will be elaborated on in section 7.2 and section 7.3 of the chapter respectively. Given the theoretical contributions and practical implications, this enquiry is faced with a number of limitations, which are identified and discussed in section 7.4 of the current chapter. Potential avenues for future research are also identified and discussed in section 7.5 and section 7.6 summarises the chapter.

7.2 Contributions to Knowledge

Three theoretical and methodological contributions are made in this research, which are (i) understanding the influence of government incentives on supply chain parties' decision making, (ii) the consideration of market uncertainties in policy making and (iii) the consideration of green technology performance dependent incentives. Two methodological contributions are presented, (i) relaxing the assumptions of modelling research, (ii) capturing supply chain behaviour by combining optimisation and simulation methods. They are discussed in detail as follows.

7.2.1 Theoretical contribution 1 (Key theoretical contribution)

Understanding the influence of government incentives on supply chain parties' decision making

This project presents an incentive model that considers the decision making of both government and supply chain parties, and thus addresses the research gap in the extant literature. In the incentive project, the government has the main role in providing incentives, and the supply chain parties are the ones who receive incentives. Both the government's and the supply chain parties' decision-makings are influential to the adoption of incentive projects and the adoption of green technology in the supply chain. However, none of the previous studies has considered both the government's and the supply chain parties' decision-makings simultaneously when discussing government incentives on green technology. Several scholars have investigated the management of incentive policy from the government's perspective (Baldwin & Krugman, 2004; Boskin & Sheshinski, 1978; Chappin et al., 2009; Clemens, 2006; Cohen et al., 2015; Coria, 2009; Diamond, 2009; Dowson et al., 2012; Gallagher & Muehlegger, 2011; Goulder & Mathai, 2000; Jena et al., 2018; Zhang & Wang, 2017). Others have addressed the supply chain's operational strategies/decisions with government green incentives from the manufacturer's perspective (Fischer et al., 2003; Goulder & Mathai, 2000; Krass et al., 2013). This marks a research gap in the literature. Although some scholars have attempted to model the interaction between supply chain decision makers (Sheu & Chen, 2012; Xie, 2015) and the interaction between a single supply chain party and the government, the above research gap has yet to be effectively addressed. This study has built an incentive model to formulate the decision making in the incentive project in the real world including government and supply chain parties. The influence of government incentive on supply chain behaviour is explained in detail in the current enquiry. Building a comprehensive model which captures in detail the decision flows of government incentive projects, the current project is the first to address the research gap.

7.2.2 Theoretical contribution 2

Consideration of market uncertainties in policy making

The present research considers market uncertainties including the uncertainty of price sensitivity and the uncertainty of greenness preference on demand. Uncertainty has been indicated as an essential issue that should be taken into account in modelling the market demand (Bernstein & Federgruen, 2005; Burgers et al., 1993; Cardoso et al., 2013; Gupta & Maranas, 2003; Xiao & Yang, 2008). The market environment is an important factor affecting the influence of government policy on supply chain because the expected responses from the market can change the supply chain's decision making. None of the existing literature has considered market uncertainties in government policy making, thus constituting a research gap. Since green car demand is influenced by price and green technology adoption (Pickett-Baker & Ozaki, 2008; Lee et al., 2013), and consumers' green technology and price sensitivity are not fixed in the different market environment, it is necessary to consider them into the model's formulation. In additional, by analysing the secondary data, it was also confirmed that consumers' green technology sensitivity and price sensitivity were various in the different time periods in the Taiwanese green car market. Although it is necessary to formulate the uncertainty of these two variables into market demand, this has not been studied in previous green policy management or supply chain management related research. By considering this significant factor in the incentive model, the present study thus contributes to and extends the existing knowledge.

7.2.3 Theoretical contribution 3

Consideration of green technology performance dependent incentives

In this research project, a green technology dependent incentive is considered in green policy implements. It was found that government incentives can shape the operating strategy of the supply chain (Zhao et al., 2012; Sheu & Chen, 2012), such as supply chain integration (Sheu et al., 2005). Government green incentives may not only help to promote green products to the market (Webster & Mitra, 2007; Jin, 2011), but also financially support the green technology development and adoption into the supply chain (Xu et al., 2013). Although the impact of government green incentives on green technology innovation has been popularly discussed in the existing literature (Diamond, 2009; Fischer & Newell, 2008; Phaneuf & Requate, 2002; Van Soest, 2005), previous studies tend to overlook the interplay between government green incentives and green technology adoption in some contexts. No previous investigation has considered the existing green technology dependent incentive which is currently applied in China and in the background case of this study, Taiwan. Even though China is the biggest source of greenhouse gas emission growth in the world (Boden et al., 2013), the green technology level dependent incentives have not been studied by previous research, unlike traditional green incentives which provide a constant amount of incentive to green product providers. A more realistic and efficient way of incentivising is to provide incentives to the supply chain according to their green technology performance so that the green technology improvement can be directly driven by the incentives. Although green incentive approach implementation is important, the literature fails to discuss it in the same way as investigating government green policy strategies or supply chain green technology innovation management has not been sufficiently dealt with. It is for this reason that the previous understanding of government green policy strategy and green technology innovation management in the supply chain is limited: only constant incentive has been considered instead of green technology dependent incentives. By investigating supply chain behaviour based on green technology dependent incentives provided by the government, this research enquiry presents a more valid incentive model that applies real-life green policy into a mathematical model. This project constitutes the first attempt to address this research gap and thus contributes to the existing literature.

7.2.4 Methodological contribution 1

Relaxing the assumptions of modelling research

The current study has used modelling technique to build the foundation of the model, and the qualitative method was then employed to validate and inform it. Mathematical models have been popularly applied to study policy management in the extant literature (Boskin & Sheshinski, 1978; Cohen et al., 2015; Coria, 2009; Krass et al., 2013; Jena et al., 2018). However, they tend to be highly dependent on modelling assumptions and suffer from the lack of empirical support in general. The present study contributes to the literature by addressing this research deficit. The proposed model integrates empirical information into the foundation of the incentive model, and thus relaxes the assumptions in the existing literature. Integrating information from a real case study in the industry into the mathematical model, places the proposed model on a base of empirical data instead of pure mathematical assumptions. Notably, the qualitative data collected through the interviews with supply chain practitioners do not only verify the components and cross-validates the model, but also provides explanations to the supply chain behaviour change caused by government incentives. In doing so, this research study contributes to the literature by building a more valid government incentive model to explain the influence of government incentives on supply chain behaviour and the model developed here has efficiently relaxed the assumptions in the previous studies of mathematical modelling.

7.2.5 Methodological contribution 2

Analysing supply chain behaviour making by combining optimisation and simulation methods

In order to formulate precisely a real-life decision-making process into a mathematical model, the present project has adopted a combination of optimisation and simulation methods. An optimisation-based simulation model was built to demonstrate the mechanism of green incentive policy applied in the supply chain. Supply chain parties aim to maximise short-term profit, whereas incentive projects are usually a long-term operation. Thus, an innovative approach is needed. In this study, a multiple-period simulation model was developed with the consideration of single-period optimisation in supply chain decision making. Because of the difficulty of solving multiple-period optimisation models in a close form, previous studies have only conducted a single period optimisations approach to formulating similar problems (Sheu & Chen, 2012; Xie, 2015), and lack the consideration of long-term incentive periods. In the present project, the adoption of both optimisation and simulation methods helps to overcome this difficulty. It allows the researcher to analyse not only complicated multiple-period incentive problems, but also consider single period optimisations. Having considered the supply chain's single period optimisation in a multiple-period simulation process, this model closely fits reality. Thus, this research enquiry contributes to the literature by building a more valid and efficient model which closely describes the single-period optimisation problem in the supply chain and the multiple-period decision making process of the whole incentive project.

7.3 Implications to Policy and Practice

This research study contributes to practice in two aspects. First, it provides managerial implications to green policy makers in governments. Second, it offers insights into decision making in the field of supply chain management. These two practical contributions are elaborated as follows.

7.3.1 Government policy making

This project provides insights into government policy management. It is suggested that governments should allocate resources/incentives effectively in order to maximise the efficiency of the incentives. Four incentive strategies have been proposed for government policy making; Low Incentives, High Incentives, Supplier Focus, and Manufacturer Focus strategies. High Incentive strategy leads to best green technology improvement. However, Supplier Focus or Manufacturer Focus strategies are suggested for implementation when the budget of green incentives is limited. To allocate the incentive based on a priority rather than equally share it between supplier and manufacturer is more efficient regarding the green technology improvement. This project proposes that the selection of the best incentive strategy is dependent upon market scenarios such as green car market size, the cost of green technology innovation in the supply chain, and whether product greenness is supplier-driven or manufacturer-driven. To select the appropriate incentive strategy, it is necessary to consider the market scenario. Findings of this study can help to increase green technology improvement in the supply chain by implementing an appropriate incentive strategy.

Government incentives do not affect supply chain pricing as directly as expected. This research project has found that the pricing strategy in the supply chain is affected by the green technology level, and green technology level is influenced by the incentives. Government green incentives can effectively and directly lead the supply chain to produce greener products but cannot lower the product price offered to the market. That is, the supply chain uses the government incentives to enhance their green technology, then their pricing reflects the increase of product greenness. The current enquiry suggests furthermore that governments should provide incentives directly to consumers when the economy is relatively worse than normal (economy depress) and the consumers' greenness sensitivity is low. This suggestion is because incentives on the supply chain can only benefit consumers by providing greener products but not cheaper green products with the same greenness level.

7.3.2 Supply chain management

This study provides managerial implications to supply chain decision making. First, the optimal green technology decision making for the supplier and the manufacturer with the response to the government incentive is illustrated. The incentive model provides an optimal strategy to guide the supplier and the manufacturer's determining their green technology levels given the government incentives. When the government provides incentives to the supply chain, there is a trade-off between investing the incentive money in green technology improvement or using it to reduce product price. This study contributes to supply chain management by guiding supply chain parties to make optimal decisions in response to government green incentives. Second, the optimal pricing decisions for the supplier and the manufacturer are proposed. Green technology decisions are changed by the government incentives, and the pricing in the supply chain is affected by the change of green technology. In this case, supply chain parties have to consider the incentives from the government, the expense occurred from green technology investment, and the influence of the pricing on the market demand at the same time, which is a complicated supply chain problem. This project enables the supplier and manufacturer to have clear pricing strategies when the government provides green incentives. In addition, due to the interaction between supply chain parties, it was found in this study that incentives can influence multiple supply chain parties. It is thus suggested that supply chain parties consider the incentive situation of their upstream and downstream so that the green technology and pricing decision can be made optimally.

7.4 Reflections on Research Limitations

7.4.1 Assumptions of linear demand in the model

Linear market demand function has been applied in the supply chain parties' objective functions in both Preliminary Study 1 and Main Study 3. In Main Study 3, the linear relationship between independent variables (green technology and price) and dependent variable (sales) has been confirmed by using five years' worth of (2011-2015) car registration data from Taiwan (a linear regression model was built). However, other forms of demand function could possibly be found based on different countries or different periods in the same country. Thus, the assumption of the linearity of the market demand is considered a research limitation in this project.

7.4.2 Supply chain parties considered in the model

Out of many supply chain roles, only the supplier and the manufacturer have been considered when modelling supply chain framework in both Preliminary Study 1 and Main Study 3. These two parties have been used in many previous studies to formulate a mathematic model in green supply chain management (Webster & Mitra, 2008; Chen & Sheu, 2009; Zhao, 2012) precisely because their operational decisions are more influential than those of other parties in the supply chain. Although manufacturers and suppliers usually have a significantly stronger impact on determining a car's greenness level than other supply chain parties, the rest of supply chain such as retailers and dealers could potentially influence it as well. For this reason, the lack of the consideration of other supply chain parties is considered as a limitation within this project.

7.4.3 Consideration of green policies

Although incentive policy is the most frequently studied issue in the area of green technology promotion (Coria, 2009; Fischer et al., 2003; Requate & Unold, 2003; Jung et al., 1996), other green intervention, such as tax-related green policies and government subsidies, could also influence green technology development. Due to the lack of other green policies' direct impact on the supply chain's green technology development in the interviews, green incentives were regarded in this enquiry as to the only government green policy for promoting green technology innovation. The lack of consideration of other government green interventions thus poses another limitation to this study.

7.4.4 The assumption of monopoly in the model

In the incentive model, it is assumed one supplier and one manufacturer in the supply chain. That is, the market structure is a monopoly. In the monopoly market, the competitor's price is considered as given and the influence of the monopolist's price on others' pricing strategy is ignored (Krugman & Obstfeld, 2008). The assumption of the monopoly market is adopted in the incentive models in both Preliminary Study 1 and Main Study 3 which is considered as a research limitation in this project.

7.4.5 The consideration of the source of the emissions

In this research, it is assumed that government only considers the emission produced from product use and the emissions from the production process is not included in the incentive model. This is due to the lack of evidence indicates the connection between the emission produced from the production process and the final product greenness. Although there is no relevant emission regulation that can directly drive the adoption of green technology in the background case of this research, Taiwan. The government in other countries may have published emission regulation that can directly lead the supply chain to invest in green technology. The assumption in the incentive model that the government only focuses on the emissions produced by product use but not the overall product life cycle is considered as a research limitation.

7.5 Further research

7.5.1 Non-linear demand function

A linear relation between car sales and predictors has been identified by examining five years' (2011-2015) car registration data in Taiwan. In this study, it was only assumed that a linear demand occurs in the green car market. Future researchers may consider using other forms of demand function to build the model. For example, a non-linear relationship may be found between the demand estimation and predictors. Further research may also use a different data set to test the form of the demand function.

7.5.2 The influence of other green interventions on supply chain behaviour

This study has only focused on government financial incentives provided to the supply chain. However, other green policies, such as green infrastructure deployment strategy for charging stations and emission penalty to the production process in the supply chain, are also likely to contribute to changing supply chain behaviour (Mak et al., 2013). According to the background cases of this project, the Taiwanese government aims to reduce carbon dioxide emission in the manufacturing process from 2025 which is considered to be the next step of the supply chain green technology development in Taiwan. Thus, additional green policies could be considered in the investigation of the influence of government intervention on green technology development in further research.

7.6 Chapter Summary

This chapter has presented the conclusion of the research project. First, the theoretical contributions to the literature have been discussed, and then the practical implications to supply chain management and policy management were elaborated on. Finally, discussions of research limitations were provided, and potential avenues for future research were proposed.

Reference

Abad, P. L. (1994). Supplier pricing and lot sizing when demand is price sensitive. *European Journal of Operational Research*, *78*(3), 334-354.

Ahi, P., & Searcy, C. (2013). A comparative literature analysis of definitions for green and sustainable supply chain management. *Journal of cleaner production*, *52*, 329-341.

Albareda, L., Lozano, J. M., & Ysa, T. (2007). Public policies on corporate social responsibility: The role of governments in Europe. *Journal of Business Ethics*, *74*(4), 391-407.

Ambec, S., & Lanoie, P. (2008). Does It Pay to Be Green? A Systematic Overview. *The Academy of Management Perspectives*, 45-62.

Amini, M., Wakolbinger, T., Racer, M., & Nejad M.G. (2012). Alternative supply chain production-sales policies for new product diffusion: An agent-based modelling and simulation approach. *European Journal of Operational Research, 216*(2), 301-311.

Aronson, J. (1995). A pragmatic view of thematic analysis. *The qualitative report*, 2(1), 1-3.

Arthur, W. B., Durlauf, S. N., & Lane, D. A. (1997). The economy as an evolving complex system II. Reading, MA: Addison-Wesley.

Ashby, A., Leat, M., & Hudson-Smith, M. (2012). Making connections: a review of supply chain management and sustainability literature. *Supply Chain Management: An International Journal, 17* (5), 497-516.

Baldwin, R. E., & Krugman, P. (2004). Agglomeration, integration and tax harmonisation. *European Economic Review*, *48*(1), 1-23.

Barari, S., Agarwal G., Zhang W. J., Mahanty, B., & Tiwari, M. K. (2012). A decision framework for the analysis of green supply chain contracts: An evolutionary game approach. *Expert Systems with Applications, 39*(3), 2965-2976.

Barriball L. K., & While A. (1994). Collecting Data using a semi-structured interview: a discussion paper. *Journal of advanced nursing. 19*(2), 328-335.

Baumann, H., Boons, F., & Bragd, A. (2002). Mapping the green product development field: Engineering, policy and business perspectives. *Journal of Cleaner Production, 10*(5), 409-425.

Bazan, E., Jaber, M. Y., & El Saadany, A. M. (2015). Carbon emissions and energy effects on manufacturing–remanufacturing inventory models. *Computers & Industrial Engineering*, *88*, 307-316.

Ben-Porath, E. (1997). Rationality, Nash equilibrium and backwards induction in perfect-information games. *The Review of Economic Studies*, *64*(1), 23-46.

Berg, B. L. (2004). *Qualitative research methods for the social sciences* (5th ed.). Boston: Pearson.

Bernstein, F., & Federgruen, A. (2005). Decentralized supply chains with competing retailers under demand uncertainty. *Management Science*, *51*(1), 18-29.

Bhattacharya, R. (2016). A closed loop supply chain game between a supplier and a manufacturer in a two-stage scenario. *International Journal of Logistics Systems and Management*, *23*(4), 445-475.

Bhavnani, R. (2006). Natural disaster conflicts. *Unpublished manuscript, Harvard University*.

Boden, T. A., Marland, G. & Andres, R. J. *Global, Regional, and National Fossil-Fuel CO_2 Emissions* (Oak Ridge National Laboratory, US Department of Energy, 2013).

Bonini, S. M., & Oppenheim, J. M. (2008). Helping ‘green’ products grow. *The McKinsey Quarterly*, *3*(2), 1-8.

Boskin, M. J., & Sheshinski, E. (1978). Optimal redistributive taxation when individual welfare depends upon relative income. *The Quarterly Journal of Economics*, 589-601.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, *3*(2), 77-101.

Brenner, M., Brown, J., & Canter, D. V. (1985). *The Research interview, uses and approaches*. London: Academic Press.

Brugmann, J. (1996). Planning for sustainability at the local government level. *Environmental Impact Assessment Review*, *16*(4-6), 363-379.

Bryman, A., & Bell, E. (2007). *Business research methods*. New York: Oxford University Press Inc.

Bryman, A., (2008). Social Research Methods. 3rd edition. Oxford University Press.

Burgers, W. P., Hill, C. W., & Kim, W. C. (1993). A theory of global strategic alliances: The case of the global auto industry. *Strategic management journal*, *14*(6), 419-432.

Buyukozkan, G., & Cidci, G. (2012). A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers. *Expert Systems with Applications, 39*(3), 3000-3011.

Cabral, I., Grilo, A., & Cruz-Machado, V. (2012). A decision-making model for lean, agile, resilient and green supply chain management. *International Journal of*

Production Research, 50(17), 4830-4845.

Cadden, T., Marshall, D., & Cao, G. (2013). Opposites attract: organisational culture and supply chain performance. *Supply Chain Management: an international journal*, *18*(1), 86-103.

Cai, G. G., Chiang, W. C., & Chen, X. (2011). Game theoretic pricing and ordering decisions with partial lost sales in two-stage supply chains. *International Journal of Production Economics*, *130*(2), 175-185.

Cao, J., Hu, L., & Wen, H. (2013). The incentive mechanism of green supply chain for raw material procurement. *Research Journal of Applied Sciences, Engineering and Technology, 5*(12), 3359-3363.

Cardoso, S. R., Barbosa-Póvoa, A. P. F., & Relvas, S. (2013). Design and planning of supply chains with integration of reverse logistics activities under demand uncertainty. *European Journal of Operational Research*, *226*(3), 436-451.

Carter, C. R. & Ellram, L. M. (1998). Reverse logistics: a review of the literature and framework for future investigation. *Journal of Business Logistics, 19*(1), 85-102.

Carter, C. R., & Rogers, D.S. (2008). A framework of sustainable supply chain management: Moving toward new theory. *International Journal of Physical Distribution and Logistics Management, 38*(5), 360-387.

Cecere, G., Corrocher, N., & Guerzoni, M. (2018). Price or performance? A probabilistic choice analysis of the intention to buy electric vehicles in European countries. *Energy Policy*, *118*, 19-32.

Cecere, G., Corrocher, N., Gossart, C., & Ozman, M. (2014). Lock-in and path dependence: an evolutionary approach to eco-innovations. *Journal of Evolutionary Economics*, *24*(5), 1037-1065.

Chappin, M. M. H., Vermeulen, W. J. V., Meeus, M. T. H., & Hekkert, M. P. (2009). Enhancing our understanding of the role of environmental policy in environmental innovation: Adoption explained by the accumulation of policy instruments and agent-based factors. *Environmental Science and Policy*, *12*(7), 934-947.

Chen, C. (2001). Design for the environment: A quality-based model for green product development. *Management Science*, *47*(2), 250-263.

Chen, X., Wu, S., Wang, X., & Li, D. (2018). Optimal pricing strategy for the perishable food supply chain. *International Journal of Production Research*, *57*(9), 2755-2768.

Chen, Y. J., & Sheu, J. B. (2009). Environmental-regulation pricing strategies for green supply chain management. *Transportation Research Part E: Logistics and Transportation Review, 45*(5), 667-677.

Chen, Y. S., Lai, S. B., & Wen, C. T. (2006). The influence of green innovation performance on corporate advantage in Taiwan. *Journal of business ethics*, *67*(4), 331-339.

Chung, S. H., Weaver, R. D., & Friesz, T. L. (2013). Strategic response to pollution taxes in supply chain networks: Dynamic, spatial, and organizational dimensions. *European Journal of Operational Research, 231*(2), 314-327.

Clarke, H. R., & Reed, W. J. (1994). Consumption/pollution tradeoffs in an environment vulnerable to pollution-related catastrophic collapse. *Journal of Economic Dynamics and Control, 18*(5), 991-1010.

Clemens, B. (2006). Economic incentives and small firms: does it pay to be green?. *Journal of business research*, *59*(4), 492-500.

Cohen, M. C., Lobel, R., & Perakis, G. (2015). The impact of demand uncertainty on consumer subsidies for green technology adoption. *Management Science*, *62*(5), 1235-1258.

Collis, J., & Hussey, R. (2003). *Business research : a practical guide for undergraduate and postgraduate students* (2nd ed.). Houndmills, Basingstoke, Hampshire ; New York: Palgrave Macmillan.

Coria, J. (2009). Taxes, permits, and the diffusion of a new technology. *Resource and Energy Economics, 31*(4), 249-271.

Dahlsrud, A. (2008). How corporate social responsibility is defined: An analysis of 37 definitions. *Corporate Social Responsibility and Environmental Management, 15*(1), 1-13.

Dangelico, R. M., & Pontrandolfo, P. (2010). From green product definitions and classifications to the Green Option Matrix. *Journal of Cleaner Production*, *18*(16-17), 1608-1628.

Dangelico, R. M., & Pujari, D. (2010). Mainstreaming green product innovation: Why and how companies integrate environmental sustainability. *Journal of business ethics*, *95*(3), 471-486.

Darnall, N., Jolley, G. J., & Handfield, R. (2008). Environmental management systems and green supply chain management: complements for sustainability?. *Business strategy and the environment*, *17*(1), 30-45.

Daziano, R. A., & Bolduc, D. (2013). Incorporating pro-environmental preferences towards green automobile technologies through a Bayesian hybrid choice model. *Transportmetrica A: Transport Science*, *9*(1), 74-106.

Degeratu, A. M., Rangaswamy, A., & Wu, J. (2000). Consumer choice behavior in online and traditional supermarkets: The effects of brand name, price, and other search attributes. *International Journal of research in Marketing, 17*(1), 55-78.

Diamond, D. (2009). The impact of government incentives for hybrid-electric vehicles: Evidence from US states. *Energy Policy, 37*(3), 972-983.

Dowson, M., Poole, A., Harrison, D., & Susman, G. (2012). Domestic UK retrofit challenge: Barriers, incentives and current performance leading into the Green Deal. *Energy Policy*, 50, 294-305.

Easterby-Smith, M., Thorpe, R., & Lowe, A. (1991). *Management research : an introduction*. London ; Newbury Park: Sage.

El Ouardighi, F. (2014). Supply quality management with optimal wholesale price and revenue sharing contracts: A two-stage game approach. *International Journal of Production Economics*, *156*, 260-268.

Enkvist, P.-A., Naucler, T., & Rosander, J. (2007). A cost curve for greenhouse gas reduction. *McKinsey Quarterly*, (1), 34-45.

Esmaeili, M., Aryanezhad, M. B., & Zeephongsekul, P. (2009). A game theory approach in seller–buyer supply chain. *European Journal of Operational Research*, *195*(2), 442-448.

European Commission (2011). A renewed EU strategy 2011–14 for Corporate Social Responsibility. Brussels: European Commission.

Fang, C., & Zhang, J. (2018). Performance of green supply chain management: A systematic review and meta analysis. *Journal of Cleaner Production*.

Fawcett, S. E., Osterhaus, P., Magnan, G. M., Brau, J. C., & McCarter, M. W. (2007). Information sharing and supply chain performance: The role of connectivity and willingness. *Supply Chain Management, 12*(5), 358-368.

Figge, F., & Hahn, T. (2012). Is green and profitable sustainable? Assessing the trade-off between economic and environmental aspects. *International Journal of Production Economics*, *140*(1), 92-102.

Fischer, C., & Newell, R. G. (2008). Environmental and technology policies for climate mitigation. *Journal of environmental economics and management, 55*(2), 142-162.

Fischer, C., Parry, I.W.H., & Pizer, W.A. (2003). Instrument choice for environmental protection when technological innovation is endogenous. *Journal of Environmental Economics and Management, 45*(3), 523-545.

Fish, S., & Savoie, T. B. (2001). Simulation-based optimal sizing of hybrid electric vehicle components for specific combat missions. *IEEE Transactions on Magnetics*, *37*(1), 485-488.

Fisk, P. (2010). *People, Planet, Profit: How to Embrace Sustainability for Innovation and Business Growth*. London: Kogan Page.

Flammer, C. (2015). Does corporate social responsibility lead to superior financial performance? A regression discontinuity approach. *Management Science, 61*(11), 2549-2568.

Fleischmann, M., Krikke, H. R., Dekker, R., & Flapper, S. D. P. (2000). A characterisation of logistics networks for product recovery. *Omega, 28*(6), 653-666.

Fujii, H., & Managi S. (2013). Which industry is greener? An empirical study of nine industries in OECD countries. *Energy Policy, 57*, 381-388.

Gale, D., & Stewart, F. M. (1953). Infinite games with perfect information. *Contributions to the Theory of Games*, *2*, 245-266.

Gallagher, K. S., & Muehlegger, E. (2011). Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology. *Journal of Environmental Economics and management*, *61*(1), 1-15.

Gaskell, G. (2000). *Individual and group interviewing*. Qualitative researching with text, image and sound, 38-56.

Georgiadis, P., & Vlachos, D. (2004). The effect of environmental parameters on product recovery. *European Journal of Operational Research, 157*(2), 449-464.

Ghosh, D., & Shah, J. (2012). A comparative analysis of greening policies across supply chain structures. *International Journal of Production Economics. 135*(2), 568-583.

Gill, P., Stewart, K., Treasure, E., & Chadwick, B. (2008). Methods of data collection in qualitative research: Interviews and focus groups. *British Dental Journal, 204*(6), 291-295.

Ginsberg, J. M., & Bloom, P. N. (2004). Choosing the right green-marketing strategy. *MIT Sloan Management Review*, *46*(1), 79.

Gjerdrum, J., Shah, N., & Papageorgiou, L. G. (2002). Fair transfer price and inventory holding policies in two-enterprise supply chains. *European Journal of Operational Research*, *143*(3), 582-599.

Gnann, T., Plötz, P., Kühn, A., & Wietschel, M. (2015). Modelling market diffusion of electric vehicles with real world driving data - German market and policy options. *Transportation Research Part A: Policy and Practice, 77*, 95-112.

Gond, J. P., Kang, N., & Moon, J. (2011). The government of self-regulation: On the comparative dynamics of corporate social responsibility. *Economy and society*, *40*(4), 640-671.

Goulder, L. H., & Mathai, K. (2000). Optimal CO2 abatement in the presence of induced technological change. *Journal of Environmental Economics and Management*, *39*(1), 1-38.

Graczyk, O. T. (2011). Energy subsidies harm paper manufacturers. *Przeglad Papierniczy, 67*(4), 253-254.

Graneheim, U. H., & Lundman, B. (2004). Qualitative content analysis in nursing research: concepts, procedures and measures to achieve trustworthiness. *Nurse education today*, *24*(2), 105-112.

Green, R. M., & Kellaway, M. J. (1997). *U.S. Patent No. 5,642,270*. Washington, DC: U.S. Patent and Trademark Office.

Gupta, A., & Maranas, C. D. (2003). Managing demand uncertainty in supply chain planning. *Computers & chemical engineering*, *27*(8-9), 1219-1227.

Hafezalkotob, A. (2015). Competition of two green and regular supply chains under environmental protection and revenue seeking policies of government. *Computers & Industrial Engineering*, *82*, 103-114.

Hall, B. H., & Helmers, C. (2013). Innovation and diffusion of clean/green technology: Can patent commons help?. *Journal of Environmental Economics and Management*, *66*(1), 33-51.

Hitchcock, T. (2012). Low carbon and green supply chains: The legal drivers and commercial pressures. *Supply Chain Management, 17*(1), 98-101.

Holsapple, C. W., & Joshi, K. D. (2002). Knowledge manipulation activities: Results of a Delphi study. *Information and Management, 39*(6), 477-490.

Huang, Z., & Li, S. X. (2001). Co-op advertising models in manufacturer–retailer supply chains: A game theory approach. *European journal of operational* *research*, *135*(3), 527-544.

Hüttinger, L., Schiele, H., & Schröer, D. (2014). Exploring the antecedents of preferential customer treatment by suppliers: a mixed methods approach. *Supply Chain Management: An International Journal*, *19*(5/6), 697-721.

Jaffe, A.B., Newell, R.G., Stavins, R.N. (2005). A tale of two market failures: Technology and environmental policy. *Ecological Economics*, *54*(2-3), 164-174.

Jahangirian, M., Eldabi, T., Naseer, A., Stergioulas, L. K., & Young, T. (2010). Simulation in manufacturing and business: A review. *European Journal of Operational Research, 203*(1), 1-13.

Jain, V., Wadhwa, S., & Deshmukh, S. G., (2006). Modeling and analysis of supply chain dynamics: a high intelligent time petri net based approach. *International Journal of Industrial and Systems Engineering, 1* (1/2), 59-86.

Jain, V., Wadhwa, S., & Deshmukh, S. G., (2007). Supplier selection using fuzzy association rules mining. *International Journal of Production Research, 45* (6), 1323-1353.

Jamali, D. (2006). Insights into triple bottom line integration from a learning organization perspective. *Business Process Management Journal*, *12*(6), 809-821.

Jankowicz, A. D. (2005). *Business research projects* (Fourth Edition ed.). London: Thomson Learning.

Jayaraman, V., Guide, V. D. R., & Srivastava, R., 1999. A closed-loop logistics model for remanufacturing. *Journal of the Operational Research Society, 50*(5), 497-508.

Jena, S. K., Sarmah, S. P., & Padhi, S. S. (2018). Impact of government incentive on price competition of closed-loop supply chain systems. *INFOR: Information Systems* *and Operational Research*, *56*(2), 192-224.

Jin, C. F., Wang, X., & Mei, L. J. (2011). Analysis on the optimal subsidy strategy of government in green supply chain. *Advanced Materials Research, 224*, 147-151.

Jonassen, H. D., (1991). Objectivism versus constructivism: Do we need a new philosophical paradigm? *Educational Technology Research and Development, 39*(3), 5-14.

Jung, C., Krutilla, K., & Boyd, R. (1996). Incentives for advanced pollution abatement technology at the industry level: An evaluation of policy alternatives. *Journal of Environmental Economics and Management*, *30*(1), 95-111.

Kelle, U. (2006). Combining qualitative and quantitative methods in research practice: purposes and advantages. *Qualitative research in psychology*, *3*(4), 293-311.

Koumanakos, D. P. (2008). The effect of inventory management on firm performance. *International journal of productivity and performance management*, *57*(5), 355-369.

Krass, D., Nedorezov, T., & Ovchinnikov, A. (2013). Environmental taxes and the choice of green technology. *Production and Operations Management*, *22*(5), 1035-1055.

Krutilla, K., & Graham, J. D. (2012). Are Green Vehicles Worth the Extra Cost? The Case of Diesel-Electric Hybrid Technology for Urban Delivery Vehicles. *Journal of Policy Analysis and Management, 31*(3), 501-532.

Lam, H. L., Ng, W. P. Q., Ng, R. T. L., Ng, E. H., Aziz, M. K. A., & Ng, D. K. S. (2013). Green strategy for sustainable waste-to-energy supply chain. *Energy,* article in press.

Lee, D. H., Park, S. Y., Hong, J. C., Choi, S. J., & Kim, J. W. (2013). Analysis of the energy and environmental effects of green car deployment by an integrating energy system model with a forecasting model. *Applied energy*, *103*, 306-316.

Lee, D. H., Park, S. Y., Kim, J. W., & Lee, S. K. (2013). Analysis on the feedback effect for the diffusion of innovative technologies focusing on the green car. *Technological Forecasting and Social Change*, *80*(3), 498-509.

Lee, K. H., & Kim, J. W. (2011). Integrating suppliers into green product innovation development: an empirical case study in the semiconductor industry. *Business Strategy and the Environment*, *20*(8), 527-538.

Leng, M., & Parlar, M. (2005). Game theoretic applications in supply chain management: a review. *INFOR: Information Systems and Operational Research*, *43*(3), 187-220.

Letmathe, P., & Balakrishnan, N. (2005). Environmental considerations on the optimal product mix. *European Journal of Operational Research*, *167*(2), 398-412.

Liu, X., Wang, C., Shishime, T., & Fujitsuka, T. (2012). Sustainable consumption: Green purchasing behaviours of urban residents in China. *Sustainable Development*, *20*(4), 293-308.

Lu, T.-P., Trappey, A. J. C., Chen, Y.-K., & Chang, Y.-D. (2013). Collaborative design and analysis of supply chain network management key processes model. *Journal of Network and Computer Applications, 36*(6), 1503-1511.

Lukas, E., & Welling, A. (2014). Timing and eco (nomic) efficiency of climate-friendly investments in supply chains. *European Journal of Operational Research, 233*(2), 448-457.

Ma, Y., Rong, K., Mangalagiu, D., Thornton, T. F., & Zhu, D. (2018). Co-evolution between urban sustainability and business ecosystem innovation: Evidence from the sharing mobility sector in Shanghai. *Journal of Cleaner Production*, *188*, 942-953.

Macal, C. M., & North, M. J. (2006). Tutorial on agent-based modeling and simulation part 2: How to model with agents. Proceedings - Winter Simulation Conference, art. no. 4117593, 73-83.

Mak, H.-Y., Rong, Y., & Shen, Z.-J.M. (2013). Infrastructure planning for electric vehicles with battery swapping. *Management Science, 59*(7), 1557-1575.

Malina, M. A., Nørreklit, H. S., & Selto, F. H. (2011). Lessons learned: advantages and disadvantages of mixed method research. *Qualitative Research in Accounting & Management*, *8*(1), 59-71.

Malladi, K. T., & Sowlati, T. (2018). Sustainability aspects in Inventory Routing Problem: A review of new trends in the literature. *Journal of Cleaner Production*, 197, 804-814.

Matthyssens, P. (2007). Method paradigms in purchasing and supply management: analogizing from the (old) debate in management and marketing. *Journal of Purchasing and Supply Management*, *3*(13), 219-220.

Mersky, A.C., Sprei, F., Samaras, C., & Qian, Z.S. (2016). Effectiveness of incentives on electric vehicle adoption in Norway. *Transportation Research Part D: Transport and Environment, 46*, 56-68.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis : an expanded sourcebook* (2nd ed.). Thousand Oaks: Sage Publications.

Millington, A., Eberhardt, M., & Wilkinson, B. (2005). Gift giving, guanxi and illicit payments in buyer-supplier relations in China: Analysing the experience of UK companies. *Journal of Business Ethics, 57*(3): 255-268.

Min, H. & Galle, W. (1997), “Green purchasing strategies: trends and implications”, *International Journal of Purchasing and Materials, Summer*, 10-17.

Mirhedayatian, S. M., Azadi, M., & Farzipoor Saen, R. (2013). A novel network data envelopment analysis model for evaluating green supply chain management. *International Journal of Production Economics, 147*, 544-554.

Mitra, S., & Webster, S. (2008). Competition in remanufacturing and the effects of government subsidies. *International Journal of Production Economics, 111*(2), 287-298.

Nagarajan, M., & Sošić, G. (2008). Game-theoretic analysis of cooperation among supply chain agents: Review and extensions. *European Journal of Operational Research, 187*(3), 719-745.

Nagurney, A., & Yu, M. (2012). Sustainable fashion supply chain management under oligopolistic competition and brand differentiation. *International Journal of Production Economics, 135*(2), 532-540.

Neto, J. Q. F., Bloemhof-Ruwaard, J.M., van Nunen, J.A.E.E., & van Heck, E., (2008). Designing and evaluating sustainable logistics networks. *International Journal of Production Economics, 111*(2), 195-208.

Nieuwenhuis, P., & Katsifou, E. (2015). More sustainable automotive production through understanding decoupling points in leagile manufacturing. *Journal of Cleaner Production*, *95*, 232-241.

Nieuwenhuis, P., & Wells, P. (1997). *The Death of Motoring. Car Making and Automobility in the 21st Century*.

Nieuwenhuis, P., & Wells, P. (2007). The all-steel body as a cornerstone to the foundations of the mass production car industry. *Industrial and corporate change*, *16*(2), 183-211.

Nieuwenhuis, P., Wells, P., & Vergragt, P. J. (2004). Technological change and regulation in the car industry: Introduction. *Greener Management International*, (47), 5-12.

Norman, W., & MacDonald, C. (2004). Getting to the bottom of “triple bottom line”. *Business Ethics Quarterly*, *14*(2), 243-262.

Nouira, I., Frein, Y., & Hadj-Alouane, A. B. (2014). Optimization of manufacturing systems under environmental considerations for a greenness-dependent demand. *International Journal of Production Economics*, *150*, 188-198.

Oliver, J.D., & Lee, S.-H. (2010). Hybrid car purchase intentions: A cross-cultural analysis. *Journal of Consumer Marketing, 27* (2), 96-103.

Olson, E. G. (2008). Creating an enterprise-level “green” strategy. *Journal of business strategy*, *29*(2), 22-30.

Olson, E. L. (2013). It’s not easy being green: the effects of attribute tradeoffs on green product preference and choice. *Journal of the Academy of Marketing Science*, *41*(2), 171-184.

Ottman, J. A., Stafford, E. R., & Hartman, C. L. (2006). Avoiding green marketing myopia: Ways to improve consumer appeal for environmentally preferable products. *Environment: Science and Policy for Sustainable Development*, *48*(5), 22-36.

Page, S. E. (2005). Agent based models. *The New Palgrave Dictionary of Economics. Palgrave MacMillan, New York* (2005).

Palinkas, L. A., Aarons, G. A., Horwitz, S., Chamberlain, P., Hurlburt, M., & Landsverk,

J. (2011). Mixed method designs in implementation research. *Administration and Policy in Mental Health and Mental Health Services Research*, *38*(1), 44-53.

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health and Mental Health Services Research*, *42*(5), 533-544.

Peng, H. (2013). Optimal subsidy policy for accelerating the diffusion of green products. *Journal of Industrial Engineering and Management*, *6*(2), 626-641.

Perry, P., & Towers, N. (2013). Conceptual framework development: CSR implementation in fashion supply chains. *International Journal of Physical Distribution and Logistics Management, 43*(5), 478-501.

Phaneuf, D.J., & Requate, T. (2002). Incentives for investment in advanced pollution abatement technology in emission permit markets with banking. *Environmental and Resource Economics*, *22*(3), 369-390.

Pickett-Baker J., & Ozaki, R. (2008). Pro-environmental products: Marketing influence on consumer purchase decision. *Journal of Consumer Marketing, 25*(5), 281-293.

Preuss, L. (2007). Buying into our future: sustainability initiatives in local government procurement. *Business Strategy and the Environment*, *16*(5), 354-365.

Quarshie, Ma A. M., Salmi, A., & Leuschner, R. (2016). Sustainability and corporate social responsibility in supply chains: The state of research in supply chain management and business ethics journals. *Journal of Purchasing and Supply Management*, *22*(2), 82-97.

Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Schmidt, W.-P., Suh, S., Weidema, B.P., & Pennington, D.W. (2004). Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environment International, 30*(5), 701-720.

Reny, P. J. (1993). Common belief and the theory of games with perfect information. *Journal of Economic Theory*, *59*(2), 257-274.

Requate, T., & Unold, W. (2003). Environmental policy incentives to adopt advanced abatement technology: Will the true ranking please stand up? *European Economic Review*, *47*(1), 125-146.

Reyes, P. M. (2006). A game theory approach for solving the transshipment problem: a supply chain management strategy teaching tool. *Supply Chain Management: An International Journal*, *11*(4), 288-293.

Robson, C. (2002). *Real world research : a resource for social scientists and practitioner-researchers* (2nd ed.). Oxford, UK ; Madden, Mass.: Blackwell Publishers.

Rosenthal, R. W. (1981). Games of perfect information, predatory pricing and the chain-store paradox. *Journal of Economic theory*, *25*(1), 92-100.

Saberi, S., Cruz, J. M., Sarkis, J., & Nagurney, A. (2018). A competitive multiperiod supply chain network model with freight carriers and green technology investment option. *European Journal of Operational Research*, *266*(3), 934-949.

Samir, K. S. (2007). Green supply-chain management: A state-of-the-art literature review. *International Journal of Management Review, 9*(1), 53-80.

Sang, Y. N., & Bekhet, H. A. (2015). Modelling electric vehicle usage intentions: an empirical study in Malaysia. *Journal of Cleaner Production*, *92*, 75-83.

Santa-Eulalia, L. A., Halladjian, G., D'Amours, S., & Frayret., -J.-M. (2011). Integrated methodological frameworks for modelling agent-based advanced supply chain planning systems: A systematic literature review. *Journal of Industrial Engineering and Management, 4*(4), 624-668.

Sarkis, J. (1995). Manufacturing strategy and environmental consciousness. *Technovation, 15*(2), 79-97.

Sarkis, J. (2003). A strategic decision framework for green supply chain management. *Journal of Cleaner Production, 11*(4), 397-409.

Sarkis, J., Zhu, Q., & Lai, K. H. (2011). An organizational theoretic review of green supply chain management literature. *International Journal of Production Economics, 130*(1), 1-15.

Saunders, M., Lewis, P., & Thornhill, A. (2007). *Research methods for business students* (4th ed.). Harlow, England ; New York: Financial Times/Prentice Hall.

Savaskan, R. C., Bhattacharya, S., & Van Wassenhove, L. N. (2004). Closed-loop supply chain models with product remanufacturing, *Management Science, 50*(2), 239-252.

Seuring, S., & Muller, M. (2008). Core issues in sustainable supply chain management - A Delphi study. *Business Strategy and the Environment, 17*(8), 455-466.

Seuring, S., Sarkis, J., Müller, M., & Rao, P. (2008). Sustainability and supply chain management–an introduction to the special issue, 1545-1551.

Sheu, J. B., & Chen, Y. J. (2012). Impact of government financial intervention on competition among green supply chains. *International Journal of Production Economics*, *138*(1), 201-213.

Sheu, J. B., Chou, Y. H., & Hu, C. C. (2005). An integrated logistics operational model for green-supply chain management. *Transportation Research Part E: Logistics and Transportation Review*, *41*(4), 287-313.

Sheu, J.-B. (2011). Bargaining framework for competitive green supply chains under governmental financial intervention. *Transportation Research Part E: Logistics and Transportation Review, 47*(5), 573-592.

Slats, P. A., Bhola, B., Evers, J. J., & Dijkhuizen, G. (1995). Logistic chain modelling. *European Journal of Operational Research*, *87*(1), 1-20.

Srivastava, S. K. (2007). Green supply-chain management: A state-of-the-art literature review. *International Journal of Management Reviews, 9*(1), 53-80.

Srivastava, S. K. (2007). Green supply-chain management: a state-of-the-art literature review. *International journal of management reviews*, *9*(1), 53-80.

Steurer, R., Langer, M. E., Konrad, A., & Martinuzzi, A., (2005). Corporations, stakeholders and sustainable development I: a theoretical exploration of business-society relations. *Journal of Business Ethics, 61*(3), 263-281.

Swami, S., & Shah, J. (2013). Channel coordination in green supply chain management. *Journal of the Operational Research Society, 64*(3), 336-351.

Taiwan Ministry of Economic Affairs (2011). *Industry Technology Development Program.* From https://www.moea.gov.tw/MNS/doit/content/Content.aspx?menu_id=13391

Taiwan Ministry of Economic Affairs (2016). *Innovation Technology Application and Service program.* From https://aiip.tdp.org.tw/content/application/aiip/document/guest-cntgrp-browse.php?vars=7f8ee7ff939cad420e143231f8c3de488460393101677a6ee0e6253e79d1bef02e689590d05f4c27a469fd33e15f2b01f605b0e773e4280a41c9ab14bb6aaf

271ba974d5ab73d27b886f61de2df607ddf76f4ef50b078fe1.

Taiwan Small and Medium Enterprise Administration (2016). *Small Business Innovation Research Program (SBIR).* From http://www.sbir.org.tw/INTROSBIR.

Tako, A. A., & Robinson, S. (2012). The application of discrete event simulation and system dynamics in the logistics and supply chain context. *Decision support systems*, *52*(4), 802-815.

Tellis, G. J. (1988). The price elasticity of selective demand: A meta-analysis of econometric models of sales. *Journal of Marketing Research*, 331-341.

The World Bank (2019). Final consumption expenditure data. From https://data.worldbank.org/indicator/NE.CON.TOTL.CD?view=chart.

Thierry, M., Salomon, M., Nunen, J. V., & Wassenhove, L. N. V. (1995). Strategic issues in product recovery management, *California Management Review, 37*(2), 114-135.

Tompkins, E., & Adger, W. N. (2004). Does adaptive management of natural resources enhance resilience to climate change?. *Ecology and society*, *9*(2).

Towers, N., & Burnes, B. (2008). A composite framework of supply chain management and enterprise planning for small and medium-sized manufacturing enterprises. *Supply Chain Management, 13*(5), 349-355.

TOYOTA MOTOR CORPORATION (2018). Toyota sells 1.52 million electrified vehicles in 2017, three years ahead of 2020 target. February, 2018. https://newsroom.toyota.co.jp/en/corporate/20966057.html

Tsai, W.-H., & Hung, S.-J. (2009). A fuzzy goal programming approach for green supply chain optimisation under activity-based costing and performance evaluation with a value-chain structure. *International Journal of Production Research, 47*

(18), 4991-5017.

Tsay, Y.-Y. (2009). The impacts of economic crisis on green consumption in Taiwan. PICMET: Portland International Center for Management of Engineering and Technology, Proceedings, art. no. 5261827, 2367-2374.

U.S. EPA (U.S. Environmental Protection Agency), 2016. *Inventory of U.S. greenhouse gas emissions and sinks: 1990–2014*. EPA 430-R-16-002.

Vachon, S., & Klassen, R. D., (2008). Environmental management and manufacturing performance: the role of collaboration in the supply chain. *International Journal of Production Economics, 111* (2), 299-315.

Van Marrewijk, M. (2001). The Concept and Definition of Corporate Social Responsibility. Triple P Performance Center: Amsterdam.

Van Soest, D.P. (2005). The impact of environmental policy instruments on the timing of adoption of energy-saving technologies. *Resource and Energy Economics*, *27*(3), 235-247.

Wan, X., Pekny, J. F., & Reklaitis, G. V. (2005). Simulation-based optimization with surrogate models—Application to supply chain management. *Computers & chemical engineering*, *29*(6), 1317-1328.

Wang, X., & Chan, H. K. (2013). A hierarchical fuzzy TOPSIS approach to assess improvement areas when implementing green supply chain initiatives. *International Journal of Production Research, 51*(10), 3117-3130.

Wang, X., Chan, H. K., Yee, R. W. Y., & Diaz-Rainey, I. (2012). A two-stage fuzzy-AHP model for risk assessment of implementing green initiatives in the fashion supply chain. *International Journal of Production Economics, 135*(2), 595-606.

Webster, S. & Mitra, S. (2007). Competitive strategy in remanufacturing and the impact of take-back laws. *Journal of Operations Management, 25*(6), 1123-1140.

Wells, P., & Nieuwenhuis, P. (2012). Transition failure: Understanding continuity in the automotive industry. *Technological Forecasting and Social Change*, *79*(9), 1681-1692.

Wild, N., & Zhou, L. (2011). Ethical procurement strategies for International Aid Non-Government Organisations. *Supply Chain Management, 16*(2), 110-127.

World Trade Organisation (2013). An introduction to trade and environment in the WTO. From http://www.wto.org/english/tratop_e/envir_e/envt_intro_e.htm.

Wright, G., Lawrence, M. J., & Collopy, F. (1996). The role and validity of judgment in forecasting. *International Journal of Forecasting, 12*, 1-8.

Wu, C.-C., Chou, C.-Y., & Huang, C. (2009). Optimal price, warranty length and production rate for free replacement policy in the static demand market. *Omega, 37*(1), 29-39.

www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

Xiao, T., & Yang, D. (2008). Price and service competition of supply chains with risk-averse retailers under demand uncertainty. *International Journal of Production Economics*, *114*(1), 187-200.

Xie, G. (2015). Modeling decision processes of a green supply chain with regulation on energy saving level. *Computers & Operations Research*, *54*, 266-273.

Xu, L., Mathiyazhagan, K., Govindan, K., Noorul, Haq A., Ramachandran, N.V., & Ashokkumar, A. (2013). Multiple comparative studies of green supply chain management: Pressures analysis. *Resources, Conservation and Recycling, 78*, 26-35.

Youn, S., Yang, M. G., & Roh, J. J. (2012). Extending the efficient and responsive supply chains framework to the green context. *Benchmarking, 19*(4), 463-480.

Zhang, C.-T., & Liu, L.-P. (2013). Research on coordination mechanism in three-level green supply chain under non-cooperative game. *Applied Mathematical Modeling, 37*(5), 3369-3379.

Zhang, Y. H., & Wang, Y. (2017). The impact of government incentive on the two competing supply chains under the perspective of Corporation Social Responsibility: A case study of Photovoltaic industry. *Journal of Cleaner Production*, *154*, 102-113.

Zhao, R., Neighbour, G., Han, J., McGuire, M., & Deutz, P. (2012). Using game theory to describe strategy selection for environmental risk and carbon emissions reduction in the green supply chain. *Journal of Loss Prevention in the Process Industries, 25*(6), 927-936.

Zhao, Y., Wang, S., Cheng, T. E., Yang, X., & Huang, Z. (2010). Coordination of supply chains by option contracts: A cooperative game theory approach. *European Journal of Operational Research*, *207*(2), 668-675.

Zhao, Z.-Y., Zhao X.-J., Davidson, K., & Zuo, J. (2012). A corporate social responsibility indicator system for construction enterprises. *Journal of Cleaner Production, 29*, 277-289.

Zhu, M. (2013). Research on green supply chain management and enterprise's green degree evaluation model. *Advanced Materials Research, 664*, 37-41.

Zhu, M., & Zou, Z. (2011). Green Supply Chain Management in Construction Industry. *Innovative Computing and Information, 232*, 81-86.

Zhu, Q., Sarkis, J., & Lai, K. H. (2007). Green supply chain management: pressures, practices and performance within the Chinese automobile industry. *Journal of* *cleaner production*, *15*(11-12), 1041-1052.

Zhu, Q., Sarkis, J., & Lai, K.-H. (2008). Confirmation of a measurement model for green supply chain management practices implementation. *International Journal of Production Economics, 111*(2), 261-273.

Zhuo, C., Hall B., Levendis, Y., & Richter, H. (2011). A novel technology for green(er) manufacturing of CNTs via recycling of waste plastics. *Materials Research Society Symposium Proceedings, 1317*, 15-20.

Zhuo, H., & Wei, S. (2017). Gaming of green supply chain members under government subsidies—Based on the perspective of demand uncertainty. In *Proceedings of the Tenth International Conference on Management Science and Engineering Management* (pp. 1105-1116). Springer, Singapore.

Appendix 1 : The Proof of the Optimal Solution of the Decision of the Manufacturer

The following is the proof of the optimal solution of the decision of manufacturer by hessian matrix calculation.

$$\nabla \pi_m(p, T_m) = \begin{bmatrix} \frac{\partial}{\partial p}\pi_m \\ \frac{\partial}{\partial T_m}\pi_m \end{bmatrix} = \begin{bmatrix} a - bp + c(\alpha T_s + \beta T_m) - b(p - w + T_m G_m) \\ G_m\left(a - bp + c(\alpha T_s + \beta T_m)\right) + \beta c(p - w + T_m G_m) - 2C_{tm} T_m \end{bmatrix}$$

$$X = \begin{bmatrix} p \\ T_m \end{bmatrix} = \begin{bmatrix} \frac{1}{2b}\left[a + bw + c(\alpha T_s + \beta T_m) - bT_m G_m\right] \\ \frac{-ac\beta + bcw\beta - c^2 T_s \alpha\beta - abG_m + b^2 wG_m - bcT_s \alpha G_m}{-4bC_{tm} + c^2\beta^2 + 2bc\beta G_m + b^2 G_m^2} \end{bmatrix}$$

Taking the second partial derivatives of the manufacturer's profit function π_m in equation (1) with respect to p^2 , T_m^2 , we obtain:

$$\begin{bmatrix} \frac{\partial^2}{\partial p^2}\pi_m \\ \frac{\partial^2}{\partial T_m^2}\pi_m \end{bmatrix} = \begin{bmatrix} -2b \\ 2c\beta G_m - 2C_{tm} \end{bmatrix} > 0$$

There is an optimal solution for p , T_m that will maximise the manufacturer's profit.

$$\frac{\partial^2}{\partial p^2}\pi_m = -2b$$

$$\frac{\partial^2}{\partial p \partial T_m}\pi_m = c\beta - bG_m$$

$$\frac{\partial^2}{\partial T_m^2}\pi_m = 2c\beta G_m - 2C_{tm}$$

$$h_1 = \left[\frac{\partial^2}{\partial p^2}\pi_m\right] = [-2b], |h_1| < 0$$

$$h_2 = \begin{bmatrix} \frac{\partial^2}{\partial p^2}\pi_m & \frac{\partial^2}{\partial p \partial T_m}\pi_m \\ \frac{\partial^2}{\partial T_m \partial p}\pi_m & \frac{\partial^2}{\partial T_m^2}\pi_m \end{bmatrix} = \begin{bmatrix} -2b & c\beta - bG_m \\ c\beta - bG_m & 2c\beta G_m - 2C_{tm} \end{bmatrix}, |h_2| > 0$$

From the above calculations, it is conformed that there is a unique optimal solution which globally maximises the manufacturer's profit at $\left(p^*, T_m^*\right)$.

Appendix 2: The Proof of the Optimal Solution of the Decision of the Supplier

The following is the proof of the optimal solution of the decision of supplier by hessian matrix calculation.

$$\pi_s(w,T_s) = (w - C_s + T_s G_s)\left(a - bp^* + c\left(\alpha T_s + \beta T_m^*\right)\right) - T_s^2 C_{ts}$$

$$= (w - C_s + T_s G_s)\left(a - b\left(\frac{a + wb + c\alpha T}{2b}\right.\right.$$

$$\left.+\frac{(c\beta - bG_m)}{2b}\left(\frac{-ac\beta + bcw\beta - c^2 T_s \alpha\beta - abG_m + b^2 wG_m - bcT_s \alpha G_m}{-4bC_{tm} + c^2\beta^2 + 2bc\beta G_m + b^2 G_m^2}\right)\right)$$

$$\left.+c\left(\alpha T_s + \beta\left(\frac{-ac\beta + bcw\beta - c^2 T_s \alpha\beta - abG_m + b^2 wG_m - bcT_s \alpha G_m}{-4bC_{tm} + c^2\beta^2 + 2bc\beta G_m + b^2 G_m^2}\right)\right)\right) - T_s^2 C_{ts}$$

$$\begin{bmatrix} \dfrac{\partial^2}{\partial w^2}\pi_s \\ \dfrac{\partial^2}{\partial T_s^2}\pi_s \end{bmatrix} = \begin{bmatrix} \dfrac{c\beta b(bG_m + c\beta)}{4bC_{tm} - b^2 G_m^2 - 2bG_m c\beta - c^2\beta^2} - b \\ 2G_s\left(\dfrac{c^2\alpha\beta(bG_m + c\beta)}{2b^2 G_m^2 + 4bG_m c\beta + 2c^2\beta^2 - 8bC_{tm}} - \dfrac{1}{2}c\alpha\right) - 2C_{ts} \end{bmatrix} > 0$$

There is an optimal solution for w , T_s that will maximise the supplier's profit.

$$\frac{\partial^2}{\partial w^2}\pi_s = \frac{c\beta b(bG_m + c\beta)}{4bC_{tm} - b^2 G_m^2 - 2bG_m c\beta - c^2\beta^2} - b$$

$$\frac{\partial^2}{\partial w \partial T_s}\pi_s = G_s\left(\frac{1}{2}\frac{c\beta b(bG_m + c\beta)}{4bC_{tm} - b^2 G_m^2 - 2bG_m c\beta - c^2\beta^2} - \frac{1}{2}b\right)$$

$$+\frac{c^2\alpha\beta(bG_m + c\beta)}{2b^2 G_m^2 + 4bG_m c\beta + 2c^2\beta^2 - 8bC_{tm}} - \frac{1}{2}c\alpha$$

$$\frac{\partial^2}{\partial T_s^2}\pi_s = 2G_s\left(\frac{c^2\alpha\beta(bG_m + c\beta)}{2b^2 G_m^2 + 4bG_m c\beta + 2c^2\beta^2 - 8bC_{tm}} - \frac{1}{2}c\alpha\right) - 2C_{ts}$$

$$h_1 = \left[\frac{\partial^2}{\partial w^2}\pi_s\right] = \left[\frac{c\beta b(bG_m + c\beta)}{4bC_{tm} - b^2 G_m^2 - 2bG_m c\beta - c^2\beta^2} - b\right], |h_1| < 0$$

$$h_2 = \begin{bmatrix} \frac{\partial^2}{\partial w^2}\pi_s & \frac{\partial^2}{\partial w \partial T_s}\pi_s \\ \frac{\partial^2}{\partial T_s \partial w}\pi_s & \frac{\partial^2}{\partial T_s^2}\pi_s \end{bmatrix}, |h_2| > 0$$

From the above calculations, it is conformed that there is a unique optimal solution which globally maximises the supplier's profit at $\left(w^*, T_s^*\right)$.

Appendix 3: Optimal Solution for the Supplier's Decisions

Symbols are presented following:

$$T_s = t, T_m = T, G_s = g, G_m = G, C_s = s, \alpha = x, \beta = y, C_{tm} = C, C_{ts} = K$$

$$\frac{\partial}{\partial w}\left((w-s+t\cdot g)\cdot\left(a-b\cdot\left(-\frac{1}{2}\,\frac{-a-c\,x\,t-\frac{c\,y\,(a+c\,x\,t-b\,w)\,(b\,G+c\,y)}{-b^2\,G^2-2\,b\,G\,c\,y-c^2\,y^2+4\,C\,b}-b\,w+b\,G}{b}\right)\right)+c\cdot\left(x\cdot t+y\cdot\left(\frac{(a+c\,x\,t-b\,w)\,(b\,G+c\,y)}{-b^2\,G^2-2\,b\,G\,c\,y-c^2\,y^2+4\,C\,b}\right)\right)-t^2\cdot K\right)$$

$$\frac{1}{2}\,a-\frac{1}{2}\,c\,x\,t-\frac{1}{2}\,\frac{c\,y\,(a+c\,x\,t-b\,w)\,(b\,G+c\,y)}{-b^2\,G^2-2\,b\,G\,c\,y-c^2\,y^2+4\,C\,b}-\frac{1}{2}\,b\,w+\frac{1}{2}\,b\,G+(w-s+t\,g)\left(\frac{1}{2}\,\frac{c\,y\,b\,(b\,G+c\,y)}{-b^2\,G^2-2\,b\,G\,c\,y-c^2\,y^2+4\,C\,b}-\frac{1}{2}\,b\right)-\frac{c\,y\,b\,(b\,G+c\,y)}{-b^2\,G^2-2\,b\,G\,c\,y-c^2\,y^2+4\,C\,b}$$

$$\frac{\partial}{\partial t}\left((w-s+t\cdot g)\cdot\left(a-b\cdot\left(-\frac{1}{2}\,\frac{-a-c\,x\,t-\frac{c\,y\,(a+c\,x\,t-b\,w)\,(b\,G+c\,y)}{-b^2\,G^2-2\,b\,G\,c\,y-c^2\,y^2+4\,C\,b}-b\,w+b\,G}{b}\right)\right)+c\cdot\left(x\cdot t+y\cdot\left(\frac{(a+c\,x\,t-b\,w)\,(b\,G+c\,y)}{-b^2\,G^2-2\,b\,G\,c\,y-c^2\,y^2+4\,C\,b}\right)\right)-t^2\cdot K\right)$$

$$g\left(\frac{1}{2}\,a-\frac{1}{2}\,c\,x\,t-\frac{1}{2}\,\frac{c\,y\,(a+c\,x\,t-b\,w)\,(b\,G+c\,y)}{-b^2\,G^2-2\,b\,G\,c\,y-c^2\,y^2+4\,C\,b}-\frac{1}{2}\,b\,w+\frac{1}{2}\,b\,G\right)+(w-s+t\,g)\left(-\frac{1}{2}\,c\,x-\frac{1}{2}\,\frac{c^2\,y\,x\,(b\,G+c\,y)}{-b^2\,G^2-2\,b\,G\,c\,y-c^2\,y^2+4\,C\,b}\right)+c\left(x+\frac{y\,c\,x\,(b\,G+c\,y)}{-b^2\,G^2-2\,b\,G\,c\,y-c^2\,y^2+4\,C\,b}\right)-2\,t\,K$$

$$solve\left(\frac{1}{2}\,a-\frac{1}{2}\,c\,x\,t-\frac{1}{2}\,\frac{c\,y\,(a+c\,x\,t-b\,w)\,(b\,G+c\,y)}{-b^2\,G^2-2\,b\,G\,c\,y-c^2\,y^2+4\,C\,b}-\frac{1}{2}\,b\,w+\frac{1}{2}\,b\,G+(w-s+t\,g)\left(\frac{1}{2}\,\frac{c\,y\,b\,(b\,G+c\,y)}{-b^2\,G^2-2\,b\,G\,c\,y-c^2\,y^2+4\,C\,b}-\frac{1}{2}\,b\right)-\frac{c\,y\,b\,(b\,G+c\,y)}{-b^2\,G^2-2\,b\,G\,c\,y-c^2\,y^2+4\,C\,b}=0,\ \{w\}\right)$$

$$\left\{w=\frac{1}{2}\ \frac{1}{b\left(-3\,b\,G\,c\,y-2\,c^2\,y^2-b^2\,G^2+4\,C\,b\right)}\left(c^2\,x\,t\,b\,G\,y-3\,a\,b\,G\,c\,y+c\,x\,t\,b^2\,G^2-4\,c\,x\,t\,C\,b-a\,b^2\,G^2-2\,a\,c^2\,y^2+4\,a\,C\,b+4\,b^2\,G\,C-b^3\,G^3-2\,b^2\,G^2\,c\,y-b\,G\,c^2\,y^2-2\,c\,y\,b^2\,G-2\,b\,s\,c^2\,y^2+t\,g\,b^3\,G^2-4\,t\,g\,C\,b^2+3\,t\,g\,b^2\,G\,c\,y-2\,c^2\,y^2\,b-s\,b^3\,G^2+4\,s\,C\,b^2-3\,s\,b^2\,G\,c\,y+2\,b\,t\,g\,c^2\,y^2\right)\right\}$$

$$solve\Bigg(g\left(\frac{1}{2}\,a-\frac{1}{2}\,c\,x\,t-\frac{1}{2}\ \frac{1}{-b^2\,G^2-2\,b\,G\,c\,y-c^2\,y^2+4\,C\,b}\left(c\,y\left(a+c\,x\,t-b\left(\frac{1}{2}\ \frac{1}{b\left(-3\,b\,G\,c\,y-2\,c^2\,y^2-b^2\,G^2+4\,C\,b\right)}\left(c^2\,x\,t\,b\,G\,y-3\,a\,b\,G\,c\,y+c\,x\,t\,b^2\,G^2-4\,c\,x\,t\,C\,b-a\,b^2\,G^2-2\,a\,c^2\,y^2+4\,a\,C\,b+4\,b^2\,G\,C-b^3\,G^3-2\,b^2\,G^2\,c\,y-b\,G\,c^2\,y^2-2\,c\,y\,b^2\,G-2\,b\,s\,c^2\,y^2+t\,g\,b^3\,G^2-4\,t\,g\,C\,b^2+3\,t\,g\,b^2\,G\,c\,y-2\,c^2\,y^2\,b-s\,b^3\,G^2+4\,s\,C\,b^2-3\,s\,b^2\,G\,c\,y+2\,b\,t\,g\,c^2\,y^2\right)\right)w\right)\cdot\left(b\,G+c\,y\right)\right)-\frac{1}{2}\,b\left(\frac{1}{2}\ \frac{1}{b\left(-3\,b\,G\,c\,y-2\,c^2\,y^2-b^2\,G^2+4\,C\,b\right)}\left(c^2\,x\,t\,b\,G\,y-3\,a\,b\,G\,c\,y+c\,x\,t\,b^2\,G^2-4\,c\,x\,t\,C\,b-a\,b^2\,G^2-2\,a\,c^2\,y^2+4\,a\,C\,b+4\,b^2\,G\,C-b^3\,G^3-2\,b^2\,G^2\,c\,y-b\,G\,c^2\,y^2-2\,c\,y\,b^2\,G-2\,b\,s\,c^2\,y^2+t\,g\,b^3\,G^2-4\,t\,g\,C\,b^2+3\,t\,g\,b^2\,G\,c\,y-2\,c^2\,y^2\,b-s\,b^3\,G^2+4\,s\,C\,b^2-3\,s\,b^2\,G\,c\,y+2\,b\,t\,g\,c^2\,y^2\right)\right)+\frac{1}{2}\,b\,G\right)+\left(\left(\frac{1}{2}\ \frac{1}{b\left(-3\,b\,G\,c\,y-2\,c^2\,y^2-b^2\,G^2+4\,C\,b\right)}\left(c^2\,x\,t\,b\,G\,y-3\,a\,b\,G\,c\,y+c\,x\,t\,b^2\,G^2-4\,c\,x\,t\,C\,b-a\,b^2\,G^2-2\,a\,c^2\,y^2+4\,a\,C\,b+4\,b^2\,G\,C-b^3\,G^3-2\,b^2\,G^2\,c\,y-b\,G\,c^2\,y^2-2\,c\,y\,b^2\,G-2\,b\,s\,c^2\,y^2+t\,g\,b^3\,G^2-4\,t\,g\,C\,b^2+3\,t\,g\,b^2\,G\,c\,y-2\,c^2\,y^2\,b-s\,b^3\,G^2+4\,s\,C\,b^2-3\,s\,b^2\,G\,c\,y+2\,b\,t\,g\,c^2\,y^2\right)\right)-s+t\,g\right)\left(-\frac{1}{2}\,c\,x-\frac{1}{2}\ \frac{c^2\,y\,x\,\left(b\,G+c\,y\right)}{-b^2\,G^2-2\,b\,G\,c\,y-c^2\,y^2+4\,C\,b}\right)+c\left(x+\frac{y\,c\,x\,\left(b\,G+c\,y\right)}{-b^2\,G^2-2\,b\,G\,c\,y-c^2\,y^2+4\,C\,b}\right)-2\,t\,K=0,\ \{t\}\Bigg)$$

$$
\begin{aligned}
\{t = (&4\,g\,c\,y\,w\,s\,C\,b^3\,G + 4\,g\,c\,y\,w\,a\,C\,b^2\,G + 6\,g\,a\,c^4\,y^4 + g\,a\,b^4\,G^4 + 16\,g\,a\,C^2\,b^2 - 2\,g\,c^4\,y^4\,b \\
&- 8\,g\,b^4\,G^3\,C + 16\,g\,b^3\,G\,C^2 - 16\,g\,s\,C^2\,b^3 - g\,s\,b^5\,G^4 - c\,x\,b^4\,G^5 + 4\,c\,x\,b^4\,G^4 \\
&+ 64\,c\,x\,b^2\,C^2 - 28\,g\,a\,b^2\,G\,c\,y\,C - g\,c\,y\,w\,a\,b^3\,G^3 + 4\,g\,c\,y\,w\,b^3\,G^2\,C - g\,c\,y\,w\,s\,b^4\,G^3 \\
&- 4\,g\,c^2\,y^2\,w\,a\,b^2\,G^2 - 5\,g\,c^3\,y^3\,w\,a\,b\,G + 4\,g\,c^2\,y^2\,w\,a\,C\,b + 4\,g\,c^2\,y^2\,w\,b^2\,G\,C \\
&- 5\,g\,c^3\,y^3\,w\,b^2\,s\,G + 4\,g\,c^2\,y^2\,w\,s\,C\,b^2 - 4\,g\,c^2\,y^2\,w\,s\,b^3\,G^2 + 20\,g\,s\,C\,b^3\,G\,c\,y \\
&+ 16\,c^2\,x\,a\,b\,G\,y\,C - 16\,c^2\,x\,s\,C\,b^2\,G\,y + g\,b^5\,G^5 + 7\,g\,a\,b^3\,G^3\,c\,y + 17\,g\,a\,b\,G\,c^3\,y^3 \\
&+ 17\,g\,a\,b^2\,G^2\,c^2\,y^2 - 20\,g\,a\,c^2\,y^2\,C\,b - g\,c\,y\,w\,b^4\,G^4 - 4\,g\,c^3\,y^3\,w\,b^2\,G - 3\,g\,c^2\,y^2\,w\,b^3\,G^3 \\
&- 3\,g\,c^3\,y^3\,w\,b^2\,G^2 - g\,c^4\,y^4\,w\,b\,G - 2\,g\,c^4\,y^4\,w\,b\,s - 2\,g\,c^2\,y^2\,w\,b^3\,G^2 - 16\,g\,b^2\,G\,c^2\,y^2\,C \\
&- 24\,g\,b^3\,G^2\,C\,c\,y - 9\,g\,b^3\,s\,c^2\,y^2\,G^2 - 7\,g\,b^2\,s\,c^3\,y^3\,G + 12\,g\,b^2\,s\,c^2\,y^2\,C + 8\,g\,c\,y\,b^3\,G\,C \\
&- 5\,g\,s\,b^4\,G^3\,c\,y + 8\,c\,x\,a\,b^2\,G^2\,C - 8\,c\,x\,s\,C\,b^3\,G^2 - 4\,c^2\,x\,a\,b^2\,G^3\,y - 5\,c^3\,x\,a\,b\,G^2\,y^2 \\
&+ 4\,c^3\,x\,b\,G\,y^2\,C + 12\,c^2\,x\,b^2\,G^2\,C\,y + 5\,c^3\,x\,b^2\,s\,y^2\,G^2 + 2\,c^4\,x\,b\,s\,y^3\,G - 8\,c^3\,x\,b\,s\,y^2\,C \\
&+ 4\,c^2\,x\,s\,b^3\,G^3\,y - 56\,c^2\,x\,b^2\,G\,y\,C - 8\,g\,a\,b^3\,G^2\,C - 2\,g\,c^4\,y^4\,w\,b - 2\,g\,c^4\,y^4\,w\,a \\
&- 6\,g\,c^2\,y^2\,b^3\,G^2 - 6\,g\,c^3\,y^3\,b^2\,G + 8\,g\,c^2\,y^2\,b^2\,C + 6\,g\,b^4\,G^4\,c\,y + 12\,g\,b^3\,G^3\,c^2\,y^2 \\
&+ 10\,g\,b^2\,G^2\,c^3\,y^3 + 3\,g\,b\,G\,c^4\,y^4 - 2\,g\,b\,s\,c^4\,y^4 + 8\,g\,s\,C\,b^4\,G^2 - 2\,g\,c\,y\,b^4\,G^3 \\
&- 3\,c^2\,x\,b^3\,G^4\,y - 2\,c^4\,x\,a\,y^3\,G + 8\,c^3\,x\,a\,y^2\,C - 3\,c^3\,x\,b^2\,G^3\,y^2 - c^4\,x\,b\,G^2\,y^3 \\
&+ 14\,c^2\,x\,b^3\,G^3\,y + 16\,c^3\,x\,b^2\,G^2\,y^2 + 6\,c^4\,x\,b\,G\,y^3 - 24\,c^3\,x\,y^2\,C\,b - c\,x\,a\,b^3\,G^4 \\
&- 16\,c\,x\,a\,C^2\,b + 8\,c\,x\,b^3\,G^3\,C - 16\,c\,x\,b^2\,G\,C^2 + 16\,c\,x\,s\,C^2\,b^2 + c\,x\,s\,b^4\,G^4 \\
&- 32\,c\,x\,b^3\,G^2\,C) \Big/ (4\,g\,b^2\,c^2\,y\,w\,x\,C\,G - 2\,g^2\,b\,c^4\,y^4 + 8\,g^2\,b^4\,G^2\,C - c^2\,x^2\,b^3\,G^4 \\
&- 16\,c^2\,x^2\,b\,C^2 - 64\,K\,b^3\,G^2\,C - g^2\,b^5\,G^4 - 16\,g^2\,b^3\,C^2 + 16\,K\,c^4\,y^4 + 8\,K\,b^4\,G^4 \\
&+ 128\,K\,C^2\,b^2 + 20\,g^2\,b^3\,G\,c\,y\,C - g^2\,b^4\,c\,y\,w\,G^3 - 4\,g^2\,b^3\,c^2\,y^2\,w\,G^2 - 5\,g^2\,b^2\,c^3\,y^3\,w\,G \\
&+ 4\,g^2\,b^2\,c^2\,y^2\,w\,C - 16\,g\,b^3\,c\,x\,G^2\,C + 9\,g\,b^3\,c^2\,x\,G^3\,y + 12\,g\,b^2\,c^3\,x\,G^2\,y^2 + 5\,g\,b\,c^4\,x\,y^3\,G \\
&- 20\,g\,b\,c^3\,x\,y^2\,C + 8\,c^3\,x^2\,b\,G\,y\,C - 160\,K\,b^2\,G\,c\,y\,C + 40\,K\,b^3\,G^3\,c\,y + 72\,K\,b^2\,G^2\,c^2\,y^2 \\
&+ 56\,K\,b\,G\,c^3\,y^3 - 96\,K\,c^2\,y^2\,C\,b - 7\,g^2\,b^2\,G\,c^3\,y^3 - 9\,g^2\,b^3\,G^2\,c^2\,y^2 + 12\,g^2\,b^2\,c^2\,y^2\,C \\
&- 5\,g^2\,b^4\,G^3\,c\,y - 2\,g^2\,b\,c^4\,y^4\,w + 2\,g\,b^4\,c\,x\,G^4 + 32\,g\,b^2\,c\,x\,C^2 - 2\,c^3\,x^2\,b^2\,G^3\,y \\
&- c^4\,x^2\,b\,G^2\,y^2 + 8\,c^2\,x^2\,b^2\,G^2\,C + 4\,g^2\,b^3\,c\,y\,w\,C\,G - 36\,g\,b^2\,c^2\,x\,G\,y\,C - g\,b^3\,c^2\,y\,w\,x\,G^3 \\
&+ 4\,g\,b\,c^3\,y^2\,w\,x\,C - 2\,g\,b^2\,c^3\,y^2\,w\,x\,G^2 - g\,b\,c^4\,y^3\,w\,x\,G)\}
\end{aligned}
$$

$$w = \frac{1}{2}\ \frac{1}{b\left(-3\,b\,G\,c\,y - 2\,c^2\,y^2 - b^2\,G^2 + 4\,C\,b\right)}\left(c^2\,x\left(\left(4\,g\,c\,y\,w\,s\,C\,b^3\,G + 4\,g\,c\,y\,w\,a\,C\,b^2\,G\right.\right.\right.$$

$$+ 6\,g\,a\,c^4\,y^4 + g\,a\,b^4\,G^4 + 16\,g\,a\,C^2\,b^2 - 2\,g\,c^4\,y^4\,b - 8\,g\,b^4\,G^3\,C + 16\,g\,b^3\,G\,C^2 - 16\,g\,s\,C^2\,b^3$$

$$- g\,s\,b^5\,G^4 - c\,x\,b^4\,G^5 + 4\,c\,x\,b^4\,G^4 + 64\,c\,x\,b^2\,C^2 - 28\,g\,a\,b^2\,G\,c\,y\,C - g\,c\,y\,w\,a\,b^3\,G^3$$

$$+ 4\,g\,c\,y\,w\,b^3\,G^2\,C - g\,c\,y\,w\,s\,b^4\,G^3 - 4\,g\,c^2\,y^2\,w\,a\,b^2\,G^2 - 5\,g\,c^3\,y^3\,w\,a\,b\,G + 4\,g\,c^2\,y^2\,w\,a\,C\,b$$

$$+ 4\,g\,c^2\,y^2\,w\,b^2\,G\,C - 5\,g\,c^3\,y^3\,w\,b^2\,s\,G + 4\,g\,c^2\,y^2\,w\,s\,C\,b^2 - 4\,g\,c^2\,y^2\,w\,s\,b^3\,G^2$$

$$+ 20\,g\,s\,C\,b^3\,G\,c\,y + 16\,c^2\,x\,a\,b\,G\,y\,C - 16\,c^2\,x\,s\,C\,b^2\,G\,y + g\,b^5\,G^5 + 7\,g\,a\,b^3\,G^3\,c\,y$$

$$+ 17\,g\,a\,b\,G\,c^3\,y^3 + 17\,g\,a\,b^2\,G^2\,c^2\,y^2 - 20\,g\,a\,c^2\,y^2\,C\,b - g\,c\,y\,w\,b^4\,G^4 - 4\,g\,c^3\,y^3\,w\,b^2\,G$$

$$- 3\,g\,c^2\,y^2\,w\,b^3\,G^3 - 3\,g\,c^3\,y^3\,w\,b^2\,G^2 - g\,c^4\,y^4\,w\,b\,G - 2\,g\,c^4\,y^4\,w\,b\,s - 2\,g\,c^2\,y^2\,w\,b^3\,G^2$$

$$- 16\,g\,b^2\,G\,c^2\,y^2\,C - 24\,g\,b^3\,G^2\,C\,c\,y - 9\,g\,b^3\,s\,c^2\,y^2\,G^2 - 7\,g\,b^2\,s\,c^3\,y^3\,G + 12\,g\,b^2\,s\,c^2\,y^2\,C$$

$$+ 8\,g\,c\,y\,b^3\,G\,C - 5\,g\,s\,b^4\,G^3\,c\,y + 8\,c\,x\,a\,b^2\,G^2\,C - 8\,c\,x\,s\,C\,b^3\,G^2 - 4\,c^2\,x\,a\,b^2\,G^3\,y$$

$$- 5\,c^3\,x\,a\,b\,G^2\,y^2 + 4\,c^3\,x\,b\,G\,y^2\,C + 12\,c^2\,x\,b^2\,G^2\,C\,y + 5\,c^3\,x\,b^2\,s\,y^2\,G^2 + 2\,c^4\,x\,b\,s\,y^3\,G$$

$$- 8\,c^3\,x\,b\,s\,y^2\,C + 4\,c^2\,x\,s\,b^3\,G^3\,y - 56\,c^2\,x\,b^2\,G\,y\,C - 8\,g\,a\,b^3\,G^2\,C - 2\,g\,c^4\,y^4\,w\,b - 2\,g\,c^4\,y^4\,w\,a$$

$$- 6\,g\,c^2\,y^2\,b^3\,G^2 - 6\,g\,c^3\,y^3\,b^2\,G + 8\,g\,c^2\,y^2\,b^2\,C + 6\,g\,b^4\,G^4\,c\,y + 12\,g\,b^3\,G^3\,c^2\,y^2$$

$$+ 10\,g\,b^2\,G^2\,c^3\,y^3 + 3\,g\,b\,G\,c^4\,y^4 - 2\,g\,b\,s\,c^4\,y^4 + 8\,g\,s\,C\,b^4\,G^2 - 2\,g\,c\,y\,b^4\,G^3 - 3\,c^2\,x\,b^3\,G^4\,y$$

$$- 2\,c^4\,x\,a\,y^3\,G + 8\,c^3\,x\,a\,y^2\,C - 3\,c^3\,x\,b^2\,G^3\,y^2 - c^4\,x\,b\,G^2\,y^3 + 14\,c^2\,x\,b^3\,G^3\,y + 16\,c^3\,x\,b^2\,G^2\,y^2$$

$$+ 6\,c^4\,x\,b\,G\,y^3 - 24\,c^3\,x\,y^2\,C\,b - c\,x\,a\,b^3\,G^4 - 16\,c\,x\,a\,C^2\,b + 8\,c\,x\,b^3\,G^3\,C - 16\,c\,x\,b^2\,G\,C^2$$

$$+ 4 g c y w a C b^2 G + 6 g a c^4 y^4 + g a b^4 G^4 + 16 g a C^2 b^2 - 2 g c^4 y^4 b - 8 g b^4 G^3 C$$

$$+ 16 g b^3 G C^2 - 16 g s C^2 b^3 - g s b^5 G^4 - c x b^4 G^5 + 4 c x b^4 G^4 + 64 c x b^2 C^2$$

$$- 28 g a b^2 G c y C - g c y w a b^3 G^3 + 4 g c y w b^3 G^2 C - g c y w s b^4 G^3 - 4 g c^2 y^2 w a b^2 G^2$$

$$- 5 g c^3 y^3 w a b G + 4 g c^2 y^2 w a C b + 4 g c^2 y^2 w b^2 G C - 5 g c^3 y^3 w b^2 s G + 4 g c^2 y^2 w s C b^2$$

$$- 4 g c^2 y^2 w s b^3 G^2 + 20 g s C b^3 G c y + 16 c^2 x a b G y C - 16 c^2 x s C b^2 G y + g b^5 G^5$$

$$+ 7 g a b^3 G^3 c y + 17 g a b G c^3 y^3 + 17 g a b^2 G^2 c^2 y^2 - 20 g a c^2 y^2 C b - g c y w b^4 G^4$$

$$- 4 g c^3 y^3 w b^2 G - 3 g c^2 y^2 w b^3 G^3 - 3 g c^3 y^3 w b^2 G^2 - g c^4 y^4 w b G - 2 g c^4 y^4 w b s$$

$$- 2 g c^2 y^2 w b^3 G^2 - 16 g b^2 G c^2 y^2 C - 24 g b^3 G^2 C c y - 9 g b^3 s c^2 y^2 G^2 - 7 g b^2 s c^3 y^3 G$$

$$+ 12 g b^2 s c^2 y^2 C + 8 g c y b^3 G C - 5 g s b^4 G^3 c y + 8 c x a b^2 G^2 C - 8 c x s C b^3 G^2$$

$$- 4 c^2 x a b^2 G^3 y - 5 c^3 x a b G^2 y^2 + 4 c^3 x b G y^2 C + 12 c^2 x b^2 G^2 C y + 5 c^3 x b^2 s y^2 G^2$$

$$+ 2 c^4 x b s y^3 G - 8 c^3 x b s y^2 C + 4 c^2 x s b^3 G^3 y - 56 c^2 x b^2 G y C - 8 g a b^3 G^2 C$$

$$- 2 g c^4 y^4 w b - 2 g c^4 y^4 w a - 6 g c^2 y^2 b^3 G^2 - 6 g c^3 y^3 b^2 G + 8 g c^2 y^2 b^2 C + 6 g b^4 G^4 c y$$

$$+ 12 g b^3 G^3 c^2 y^2 + 10 g b^2 G^2 c^3 y^3 + 3 g b G c^4 y^4 - 2 g b s c^4 y^4 + 8 g s C b^4 G^2 - 2 g c y b^4 G^3$$

$$- 3 c^2 x b^3 G^4 y - 2 c^4 x a y^3 G + 8 c^3 x a y^2 C - 3 c^3 x b^2 G^3 y^2 - c^4 x b G^2 y^3 + 14 c^2 x b^3 G^3 y$$

$$+ 16 c^3 x b^2 G^2 y^2 + 6 c^4 x b G y^3 - 24 c^3 x y^2 C b - c x a b^3 G^4 - 16 c x a C^2 b + 8 c x b^3 G^3 C$$

$$- 16 c x b^2 G C^2 + 16 c x s C^2 b^2 + c x s b^4 G^4 - 32 c x b^3 G^2 C) \big/ (4 g b^2 c^2 y w x C G - 2 g^2 b c^4 y^4$$

$$+ 8 g^2 b^4 G^2 C - c^2 x^2 b^3 G^4 - 16 c^2 x^2 b C^2 - 64 K b^3 G^2 C - g^2 b^5 G^4 - 16 g^2 b^3 C^2 + 16 K c^4 y^4$$

$$+ 8 K b^4 G^4 + 128 K C^2 b^2 + 20 g^2 b^3 G c y C - g^2 b^4 c y w G^3 - 4 g^2 b^3 c^2 y^2 w G^2$$

$$- 5 g^2 b^2 c^3 y^3 w G + 4 g^2 b^2 c^2 y^2 w C - 16 g b^3 c x G^2 C + 9 g b^3 c^2 x G^3 y + 12 g b^2 c^3 x G^2 y^2$$

$$+ 5 g b c^4 x y^3 G - 20 g b c^3 x y^2 C + 8 c^3 x^2 b G y C - 160 K b^2 G c y C + 40 K b^3 G^3 c y$$

$$+ 72 K b^2 G^2 c^2 y^2 + 56 K b G c^3 y^3 - 96 K c^2 y^2 C b - 7 g^2 b^2 G c^3 y^3 - 9 g^2 b^3 G^2 c^2 y^2$$

$$+ 12 g^2 b^2 c^2 y^2 C - 5 g^2 b^4 G^3 c y - 2 g^2 b c^4 y^4 w + 2 g b^4 c x G^4 + 32 g b^2 c x C^2 - 2 c^3 x^2 b^2 G^3 y$$

$$- c^4 x^2 b G^2 y^2 + 8 c^2 x^2 b^2 G^2 C + 4 g^2 b^3 c y w C G - 36 g b^2 c^2 x G y C - g b^3 c^2 y w x G^3$$

$$+ 4 g b c^3 y^2 w x C - 2 g b^2 c^3 y^2 w x G^2 - g b c^4 y^3 w x G) b^2 G^2 - 4 c x \Big((4 g c y w s C b^3 G$$

$$+ 4 g c y w a C b^2 G + 6 g a c^4 y^4 + g a b^4 G^4 + 16 g a C^2 b^2 - 2 g c^4 y^4 b - 8 g b^4 G^3 C$$

$$+ 16 g b^3 G C^2 - 16 g s C^2 b^3 - g s b^5 G^4 - c x b^4 G^5 + 4 c x b^4 G^4 + 64 c x b^2 C^2$$

$$- 28 g a b^2 G c y C - g c y w a b^3 G^3 + 4 g c y w b^3 G^2 C - g c y w s b^4 G^3 - 4 g c^2 y^2 w a b^2 G^2$$

$$- 5 g c^3 y^3 w a b G + 4 g c^2 y^2 w a C b + 4 g c^2 y^2 w b^2 G C - 5 g c^3 y^3 w b^2 s G + 4 g c^2 y^2 w s C b^2$$

$$- 4 g c^2 y^2 w s b^3 G^2 + 20 g s C b^3 G c y + 16 c^2 x a b G y C - 16 c^2 x s C b^2 G y + g b^5 G^5$$

$$+ 7 g a b^3 G^3 c y + 17 g a b G c^3 y^3 + 17 g a b^2 G^2 c^2 y^2 - 20 g a c^2 y^2 C b - g c y w b^4 G^4$$

$$- 4 g c^3 y^3 w b^2 G - 3 g c^2 y^2 w b^3 G^3 - 3 g c^3 y^3 w b^2 G^2 - g c^4 y^4 w b G - 2 g c^4 y^4 w b s$$

$$- 2 g c^2 y^2 w b^3 G^2 - 16 g b^2 G c^2 y^2 C - 24 g b^3 G^2 C c y - 9 g b^3 s c^2 y^2 G^2 - 7 g b^2 s c^3 y^3 G$$

$$+ 12 g b^2 s c^2 y^2 C + 8 g c y b^3 G C - 5 g s b^4 G^3 c y + 8 c x a b^2 G^2 C - 8 c x s C b^3 G^2$$

$$- 4 c^2 x a b^2 G^3 y - 5 c^3 x a b G^2 y^2 + 4 c^3 x b G y^2 C + 12 c^2 x b^2 G^2 C y + 5 c^3 x b^2 s y^2 G^2$$

$$+ 2 c^4 x b s y^3 G - 8 c^3 x b s y^2 C + 4 c^2 x s b^3 G^3 y - 56 c^2 x b^2 G y C - 8 g a b^3 G^2 C$$

$$- 2 g c^4 y^4 w b - 2 g c^4 y^4 w a - 6 g c^2 y^2 b^3 G^2 - 6 g c^3 y^3 b^2 G + 8 g c^2 y^2 b^2 C + 6 g b^4 G^4 c y$$

$$+ 12 g b^3 G^3 c^2 y^2 + 10 g b^2 G^2 c^3 y^3 + 3 g b G c^4 y^4 - 2 g b s c^4 y^4 + 8 g s C b^4 G^2 - 2 g c y b^4 G^3$$

$$- 3 c^2 x b^3 G^4 y - 2 c^4 x a y^3 G + 8 c^3 x a y^2 C - 3 c^3 x b^2 G^3 y^2 - c^4 x b G^2 y^3 + 14 c^2 x b^3 G^3 y$$

$$+ 16 c^3 x b^2 G^2 y^2 + 6 c^4 x b G y^3 - 24 c^3 x y^2 C b - c x a b^3 G^4 - 16 c x a C^2 b + 8 c x b^3 G^3 C$$

$$- 16 c x b^2 G C^2 + 16 c x s C^2 b^2 + c x s b^4 G^4 - 32 c x b^3 G^2 C) \Big/ (4 g b^2 c^2 y w x C G - 2 g^2 b c^4 y^4$$

$$+ 8 g^2 b^4 G^2 C - c^2 x^2 b^3 G^4 - 16 c^2 x^2 b C^2 - 64 K b^3 G^2 C - g^2 b^5 G^4 - 16 g^2 b^3 C^2 + 16 K c^4 y^4$$

$$+ 8 K b^4 G^4 + 128 K C^2 b^2 + 20 g^2 b^3 G c y C - g^2 b^4 c y w G^3 - 4 g^2 b^3 c^2 y^2 w G^2$$

$$- 5 g^2 b^2 c^3 y^3 w G + 4 g^2 b^2 c^2 y^2 w C - 16 g b^3 c x G^2 C + 9 g b^3 c^2 x G^3 y + 12 g b^2 c^3 x G^2 y^2$$

$$+ 8 K b^4 G^4 + 128 K C^2 b^2 + 20 g^2 b^3 G c y C - g^2 b^4 c y w G^3 - 4 g^2 b^3 c^2 y^2 w G^2$$

$$- 5 g^2 b^2 c^3 y^3 w G + 4 g^2 b^2 c^2 y^2 w C - 16 g b^3 c x G^2 C + 9 g b^3 c^2 x G^3 y + 12 g b^2 c^3 x G^2 y^2$$

$$+ 5 g b c^4 x y^3 G - 20 g b c^3 x y^2 C + 8 c^3 x^2 b G y C - 160 K b^2 G c y C + 40 K b^3 G^3 c y$$

$$+ 72 K b^2 G^2 c^2 y^2 + 56 K b G c^3 y^3 - 96 K c^2 y^2 C b - 7 g^2 b^2 G c^3 y^3 - 9 g^2 b^3 G^2 c^2 y^2$$

$$+ 12 g^2 b^2 c^2 y^2 C - 5 g^2 b^4 G^3 c y - 2 g^2 b c^4 y^4 w + 2 g b^4 c x G^4 + 32 g b^2 c x C^2 - 2 c^3 x^2 b^2 G^3 y$$

$$- c^4 x^2 b G^2 y^2 + 8 c^2 x^2 b^2 G^2 C + 4 g^2 b^3 c y w C G - 36 g b^2 c^2 x G y C - g b^3 c^2 y w x G^3$$

$$+ 4 g b c^3 y^2 w x C - 2 g b^2 c^3 y^2 w x G^2 - g b c^4 y^3 w x G) C b - a b^2 G^2 - 2 a c^2 y^2 + 4 a C b$$

$$+ 4 b^2 G C - b^3 G^3 - 2 b^2 G^2 c y - b G c^2 y^2 - 2 c y b^2 G - 2 b s c^2 y^2 + \Big((4 g c y w s C b^3 G$$

$$+ 4 g c y w a C b^2 G + 6 g a c^4 y^4 + g a b^4 G^4 + 16 g a C^2 b^2 - 2 g c^4 y^4 b - 8 g b^4 G^3 C$$

$$+ 16 g b^3 G C^2 - 16 g s C^2 b^3 - g s b^5 G^4 - c x b^4 G^5 + 4 c x b^4 G^4 + 64 c x b^2 C^2$$

$$- 28 g a b^2 G c y C - g c y w a b^3 G^3 + 4 g c y w b^3 G^2 C - g c y w s b^4 G^3 - 4 g c^2 y^2 w a b^2 G^2$$

$$- 5 g c^3 y^3 w a b G + 4 g c^2 y^2 w a C b + 4 g c^2 y^2 w b^2 G C - 5 g c^3 y^3 w b^2 s G + 4 g c^2 y^2 w s C b^2$$

$$- 4 g c^2 y^2 w s b^3 G^2 + 20 g s C b^3 G c y + 16 c^2 x a b G y C - 16 c^2 x s C b^2 G y + g b^5 G^5$$

$$+ 7 g a b^3 G^3 c y + 17 g a b G c^3 y^3 + 17 g a b^2 G^2 c^2 y^2 - 20 g a c^2 y^2 C b - g c y w b^4 G^4$$

$$- 4 g c^3 y^3 w b^2 G - 3 g c^2 y^2 w b^3 G^3 - 3 g c^3 y^3 w b^2 G^2 - g c^4 y^4 w b G - 2 g c^4 y^4 w b s$$

$$- 2 g c^2 y^2 w b^3 G^2 - 16 g b^2 G c^2 y^2 C - 24 g b^3 G^2 C c y - 9 g b^3 s c^2 y^2 G^2 - 7 g b^2 s c^3 y^3 G$$

$$+ 12 g b^2 s c^2 y^2 C + 8 g c y b^3 G C - 5 g s b^4 G^3 c y + 8 c x a b^2 G^2 C - 8 c x s C b^3 G^2$$

$$- 4 c^2 x a b^2 G^3 y - 5 c^3 x a b G^2 y^2 + 4 c^3 x b G y^2 C + 12 c^2 x b^2 G^2 C y + 5 c^3 x b^2 s y^2 G^2$$

$$+ 2 c^4 x b s y^3 G - 8 c^3 x b s y^2 C + 4 c^2 x s b^3 G^3 y - 56 c^2 x b^2 G y C - 8 g a b^3 G^2 C$$

$$- 2 g c^4 y^4 w b - 2 g c^4 y^4 w a - 6 g c^2 y^2 b^3 G^2 - 6 g c^3 y^3 b^2 G + 8 g c^2 y^2 b^2 C + 6 g b^4 G^4 c y$$

$$+ 12 g b^3 G^3 c^2 y^2 + 10 g b^2 G^2 c^3 y^3 + 3 g b G c^4 y^4 - 2 g b s c^4 y^4 + 8 g s C b^4 G^2 - 2 g c y b^4 G^3$$

$$- 3 c^2 x b^3 G^4 y - 2 c^4 x a y^3 G + 8 c^3 x a y^2 C - 3 c^3 x b^2 G^3 y^2 - c^4 x b G^2 y^3 + 14 c^2 x b^3 G^3 y$$

$$+ 16 c^3 x b^2 G^2 y^2 + 6 c^4 x b G y^3 - 24 c^3 x y^2 C b - c x a b^3 G^4 - 16 c x a C^2 b + 8 c x b^3 G^3 C$$

$$- 16 c x b^2 G C^2 + 16 c x s C^2 b^2 + c x s b^4 G^4 - 32 c x b^3 G^2 C) \Big/ (4 g b^2 c^2 y w x C G - 2 g^2 b c^4 y^4$$

$$+ 8 g^2 b^4 G^2 C - c^2 x^2 b^3 G^4 - 16 c^2 x^2 b C^2 - 64 K b^3 G^2 C - g^2 b^5 G^4 - 16 g^2 b^3 C^2 + 16 K c^4 y^4$$

$$+ 8 K b^4 G^4 + 128 K C^2 b^2 + 20 g^2 b^3 G c y C - g^2 b^4 c y w G^3 - 4 g^2 b^3 c^2 y^2 w G^2$$

$$- 5 g^2 b^2 c^3 y^3 w G + 4 g^2 b^2 c^2 y^2 w C - 16 g b^3 c x G^2 C + 9 g b^3 c^2 x G^3 y + 12 g b^2 c^3 x G^2 y^2$$

$$+ 5 g b c^4 x y^3 G - 20 g b c^3 x y^2 C + 8 c^3 x^2 b G y C - 160 K b^2 G c y C + 40 K b^3 G^3 c y$$

$$+72Kb^2G^2c^2y^2+56KbGc^3y^3-96Kc^2y^2Cb-7g^2b^2Gc^3y^3-9g^2b^3G^2c^2y^2$$

$$+12g^2b^2c^2y^2C-5g^2b^4G^3cy-2g^2bc^4y^4w+2gb^4cxG^4+32gb^2cxC^2-2c^3x^2b^2G^3y$$

$$-c^4x^2bG^2y^2+8c^2x^2b^2G^2C+4g^2b^3cywCG-36gb^2c^2xGyC-gb^3c^2ywxG^3$$

$$+4gbc^3y^2wxC-2gb^2c^3y^2wxG^2-gbc^4y^3wxG)gb^3G^2-4\Big((4gcywsCb^3G$$

$$+4gcywaCb^2G+6gac^4y^4+gab^4G^4+16gaC^2b^2-2gc^4y^4b-8gb^4G^3C$$

$$+16gb^3GC^2-16gsC^2b^3-gsb^5G^4-cxb^4G^5+4cxb^4G^4+64cxb^2C^2$$

$$-28gab^2GcyC-gcywab^3G^3+4gcywb^3G^2C-gcywsb^4G^3-4gc^2y^2wab^2G^2$$

$$-5gc^3y^3wabG+4gc^2y^2waCb+4gc^2y^2wb^2GC-5gc^3y^3wb^2sG+4gc^2y^2wsCb^2$$

$$-4gc^2y^2wsb^3G^2+20gsCb^3Gcy+16c^2xabGyC-16c^2xsCb^2Gy+gb^5G^5$$

$$+7gab^3G^3cy+17gabGc^3y^3+17gab^2G^2c^2y^2-20gac^2y^2Cb-gcywb^4G^4$$

$$-4gc^3y^3wb^2G-3gc^2y^2wb^3G^3-3gc^3y^3wb^2G^2-gc^4y^4wbG-2gc^4y^4wbs$$

$$-2gc^2y^2wb^3G^2-16gb^2Gc^2y^2C-24gb^3G^2Ccy-9gb^3sc^2y^2G^2-7gb^2sc^3y^3G$$

$$+12gb^2sc^2y^2C+8gcyb^3GC-5gsb^4G^3cy+8cxab^2G^2C-8cxsCb^3G^2$$

$$-4c^2xab^2G^3y-5c^3xabG^2y^2+4c^3xbGy^2C+12c^2xb^2G^2Cy+5c^3xb^2sy^2G^2$$

$$+2c^4xbsy^3G-8c^3xbsy^2C+4c^2xsb^3G^3y-56c^2xb^2GyC-8gab^3G^2C$$

$$-2gc^4y^4wb-2gc^4y^4wa-6gc^2y^2b^3G^2-6gc^3y^3b^2G+8gc^2y^2b^2C+6gb^4G^4cy$$

$$+12gb^3G^3c^2y^2+10gb^2G^2c^3y^3+3gbGc^4y^4-2gbsc^4y^4+8gsCb^4G^2-2gcyb^4G^3$$

$$-3c^2xb^3G^4y-2c^4xay^3G+8c^3xay^2C-3c^3xb^2G^3y^2-c^4xbG^2y^3+14c^2xb^3G^3y$$

$$+16c^3xb^2G^2y^2+6c^4xbGy^3-24c^3xy^2Cb-cxab^3G^4-16cxaC^2b+8cxb^3G^3C$$

$$-16cxb^2GC^2+16cxsC^2b^2+cxsb^4G^4-32cxb^3G^2C)\big/(4gb^2c^2ywxCG-2g^2bc^4y^4$$

$$+8g^2b^4G^2C-c^2x^2b^3G^4-16c^2x^2bC^2-64Kb^3G^2C-g^2b^5G^4-16g^2b^3C^2+16Kc^4y^4$$

$$+8Kb^4G^4+128KC^2b^2+20g^2b^3GcyC-g^2b^4cywG^3-4g^2b^3c^2y^2wG^2$$

$$-5g^2b^2c^3y^3wG+4g^2b^2c^2y^2wC-16gb^3cxG^2C+9gb^3c^2xG^3y+12gb^2c^3xG^2y^2$$

$$+5gbc^4xy^3G-20gbc^3xy^2C+8c^3x^2bGyC-160Kb^2GcyC+40Kb^3G^3cy$$

$$+72\,K\,b^2\,G^2\,c^2\,y^2+56\,K\,b\,G\,c^3\,y^3-96\,K\,c^2\,y^2\,C\,b-7\,g^2\,b^2\,G\,c^3\,y^3-9\,g^2\,b^3\,G^2\,c^2\,y^2$$

$$+12\,g^2\,b^2\,c^2\,y^2\,C-5\,g^2\,b^4\,G^3\,c\,y-2\,g^2\,b\,c^4\,y^4\,w+2\,g\,b^4\,c\,x\,G^4+32\,g\,b^2\,c\,x\,C^2-2\,c^3\,x^2\,b^2\,G^3\,y$$

$$-c^4\,x^2\,b\,G^2\,y^2+8\,c^2\,x^2\,b^2\,G^2\,C+4\,g^2\,b^3\,c\,y\,w\,C\,G-36\,g\,b^2\,c^2\,x\,G\,y\,C-g\,b^3\,c^2\,y\,w\,x\,G^3$$

$$+4\,g\,b\,c^3\,y^2\,w\,x\,C-2\,g\,b^2\,c^3\,y^2\,w\,x\,G^2-g\,b\,c^4\,y^3\,w\,x\,G)\,g\,C\,b^2+3\,\Big((4\,g\,c\,y\,w\,s\,C\,b^3\,G$$

$$+4\,g\,c\,y\,w\,a\,C\,b^2\,G+6\,g\,a\,c^4\,y^4+g\,a\,b^4\,G^4+16\,g\,a\,C^2\,b^2-2\,g\,c^4\,y^4\,b-8\,g\,b^4\,G^3\,C$$

$$+16\,g\,b^3\,G\,C^2-16\,g\,s\,C^2\,b^3-g\,s\,b^5\,G^4-c\,x\,b^4\,G^5+4\,c\,x\,b^4\,G^4+64\,c\,x\,b^2\,C^2$$

$$-28\,g\,a\,b^2\,G\,c\,y\,C-g\,c\,y\,w\,a\,b^3\,G^3+4\,g\,c\,y\,w\,b^3\,G^2\,C-g\,c\,y\,w\,s\,b^4\,G^3-4\,g\,c^2\,y^2\,w\,a\,b^2\,G^2$$

$$-5\,g\,c^3\,y^3\,w\,a\,b\,G+4\,g\,c^2\,y^2\,w\,a\,C\,b+4\,g\,c^2\,y^2\,w\,b^2\,G\,C-5\,g\,c^3\,y^3\,w\,b^2\,s\,G+4\,g\,c^2\,y^2\,w\,s\,C\,b^2$$

$$-4\,g\,c^2\,y^2\,w\,s\,b^3\,G^2+20\,g\,s\,C\,b^3\,G\,c\,y+16\,c^2\,x\,a\,b\,G\,y\,C-16\,c^2\,x\,s\,C\,b^2\,G\,y+g\,b^5\,G^5$$

$$+7\,g\,a\,b^3\,G^3\,c\,y+17\,g\,a\,b\,G\,c^3\,y^3+17\,g\,a\,b^2\,G^2\,c^2\,y^2-20\,g\,a\,c^2\,y^2\,C\,b-g\,c\,y\,w\,b^4\,G^4$$

$$-4\,g\,c^3\,y^3\,w\,b^2\,G-3\,g\,c^2\,y^2\,w\,b^3\,G^3-3\,g\,c^3\,y^3\,w\,b^2\,G^2-g\,c^4\,y^4\,w\,b\,G-2\,g\,c^4\,y^4\,w\,b\,s$$

$$-2\,g\,c^2\,y^2\,w\,b^3\,G^2-16\,g\,b^2\,G\,c^2\,y^2\,C-24\,g\,b^3\,G^2\,C\,c\,y-9\,g\,b^3\,s\,c^2\,y^2\,G^2-7\,g\,b^2\,s\,c^3\,y^3\,G$$

$$+12\,g\,b^2\,s\,c^2\,y^2\,C+8\,g\,c\,y\,b^3\,G\,C-5\,g\,s\,b^4\,G^3\,c\,y+8\,c\,x\,a\,b^2\,G^2\,C-8\,c\,x\,s\,C\,b^3\,G^2$$

$$-4\,c^2\,x\,a\,b^2\,G^3\,y-5\,c^3\,x\,a\,b\,G^2\,y^2+4\,c^3\,x\,b\,G\,y^2\,C+12\,c^2\,x\,b^2\,G^2\,C\,y+5\,c^3\,x\,b^2\,s\,y^2\,G^2$$

$$+2\,c^4\,x\,b\,s\,y^3\,G-8\,c^3\,x\,b\,s\,y^2\,C+4\,c^2\,x\,s\,b^3\,G^3\,y-56\,c^2\,x\,b^2\,G\,y\,C-8\,g\,a\,b^3\,G^2\,C$$

$$-2\,g\,c^4\,y^4\,w\,b-2\,g\,c^4\,y^4\,w\,a-6\,g\,c^2\,y^2\,b^3\,G^2-6\,g\,c^3\,y^3\,b^2\,G+8\,g\,c^2\,y^2\,b^2\,C+6\,g\,b^4\,G^4\,c\,y$$

$$+12\,g\,b^3\,G^3\,c^2\,y^2+10\,g\,b^2\,G^2\,c^3\,y^3+3\,g\,b\,G\,c^4\,y^4-2\,g\,b\,s\,c^4\,y^4+8\,g\,s\,C\,b^4\,G^2-2\,g\,c\,y\,b^4\,G^3$$

$$-3\,c^2\,x\,b^3\,G^4\,y-2\,c^4\,x\,a\,y^3\,G+8\,c^3\,x\,a\,y^2\,C-3\,c^3\,x\,b^2\,G^3\,y^2-c^4\,x\,b\,G^2\,y^3+14\,c^2\,x\,b^3\,G^3\,y$$

$$+16\,c^3\,x\,b^2\,G^2\,y^2+6\,c^4\,x\,b\,G\,y^3-24\,c^3\,x\,y^2\,C\,b-c\,x\,a\,b^3\,G^4-16\,c\,x\,a\,C^2\,b+8\,c\,x\,b^3\,G^3\,C$$

$$-16\,c\,x\,b^2\,G\,C^2+16\,c\,x\,s\,C^2\,b^2+c\,x\,s\,b^4\,G^4-32\,c\,x\,b^3\,G^2\,C)\,\big/\,(4\,g\,b^2\,c^2\,y\,w\,x\,C\,G-2\,g^2\,b\,c^4\,y^4$$

$$+8\,g^2\,b^4\,G^2\,C-c^2\,x^2\,b^3\,G^4-16\,c^2\,x^2\,b\,C^2-64\,K\,b^3\,G^2\,C-g^2\,b^5\,G^4-16\,g^2\,b^3\,C^2+16\,K\,c^4\,y^4$$

$$+8\,K\,b^4\,G^4+128\,K\,C^2\,b^2+20\,g^2\,b^3\,G\,c\,y\,C-g^2\,b^4\,c\,y\,w\,G^3-4\,g^2\,b^3\,c^2\,y^2\,w\,G^2$$

$$-5\,g^2\,b^2\,c^3\,y^3\,w\,G+4\,g^2\,b^2\,c^2\,y^2\,w\,C-16\,g\,b^3\,c\,x\,G^2\,C+9\,g\,b^3\,c^2\,x\,G^3\,y+12\,g\,b^2\,c^3\,x\,G^2\,y^2$$

$$+5\,g\,b\,c^4\,x\,y^3\,G-20\,g\,b\,c^3\,x\,y^2\,C+8\,c^3\,x^2\,b\,G\,y\,C-160\,K\,b^2\,G\,c\,y\,C+40\,K\,b^3\,G^3\,c\,y$$

$$+72\,K\,b^2\,G^2\,c^2\,y^2+56\,K\,b\,G\,c^3\,y^3-96\,K\,c^2\,y^2\,C\,b-7\,g^2\,b^2\,G\,c^3\,y^3-9\,g^2\,b^3\,G^2\,c^2\,y^2$$

$$+12\,g^2\,b^2\,c^2\,y^2\,C-5\,g^2\,b^4\,G^3\,c\,y-2\,g^2\,b\,c^4\,y^4\,w+2\,g\,b^4\,c\,x\,G^4+32\,g\,b^2\,c\,x\,C^2-2\,c^3\,x^2\,b^2\,G^3\,y$$

$$-c^4\,x^2\,b\,G^2\,y^2+8\,c^2\,x^2\,b^2\,G^2\,C+4\,g^2\,b^3\,c\,y\,w\,C\,G-36\,g\,b^2\,c^2\,x\,G\,y\,C-g\,b^3\,c^2\,y\,w\,x\,G^3$$

$$+4\,g\,b\,c^3\,y^2\,w\,x\,C-2\,g\,b^2\,c^3\,y^2\,w\,x\,G^2-g\,b\,c^4\,y^3\,w\,x\,G)g\,b^2\,G\,c\,y-2\,c^2\,y^2\,b-s\,b^3\,G^2+4\,s\,C\,b^2$$

$$\begin{aligned}
&-3\,s\,b^2\,G\,c\,y+2\,b\,\big((4\,g\,c\,y\,w\,s\,C\,b^3\,G+4\,g\,c\,y\,w\,a\,C\,b^2\,G+6\,g\,a\,c^4\,y^4+g\,a\,b^4\,G^4\\
&+16\,g\,a\,C^2\,b^2-2\,g\,c^4\,y^4\,b-8\,g\,b^4\,G^3\,C+16\,g\,b^3\,G\,C^2-16\,g\,s\,C^2\,b^3-g\,s\,b^5\,G^4-c\,x\,b^4\,G^5\\
&+4\,c\,x\,b^4\,G^4+64\,c\,x\,b^2\,C^2-28\,g\,a\,b^2\,G\,c\,y\,C-g\,c\,y\,w\,a\,b^3\,G^3+4\,g\,c\,y\,w\,b^3\,G^2\,C\\
&-g\,c\,y\,w\,s\,b^4\,G^3-4\,g\,c^2\,y^2\,w\,a\,b^2\,G^2-5\,g\,c^3\,y^3\,w\,a\,b\,G+4\,g\,c^2\,y^2\,w\,a\,C\,b+4\,g\,c^2\,y^2\,w\,b^2\,G\,C\\
&-5\,g\,c^3\,y^3\,w\,b^2\,s\,G+4\,g\,c^2\,y^2\,w\,s\,C\,b^2-4\,g\,c^2\,y^2\,w\,s\,b^3\,G^2+20\,g\,s\,C\,b^3\,G\,c\,y+16\,c^2\,x\,a\,b\,G\,y\,C\\
&-16\,c^2\,x\,s\,C\,b^2\,G\,y+g\,b^5\,G^5+7\,g\,a\,b^3\,G^3\,c\,y+17\,g\,a\,b\,G\,c^3\,y^3+17\,g\,a\,b^2\,G^2\,c^2\,y^2\\
&-20\,g\,a\,c^2\,y^2\,C\,b-g\,c\,y\,w\,b^4\,G^4-4\,g\,c^3\,y^3\,w\,b^2\,G-3\,g\,c^2\,y^2\,w\,b^3\,G^3-3\,g\,c^3\,y^3\,w\,b^2\,G^2\\
&-g\,c^4\,y^4\,w\,b\,G-2\,g\,c^4\,y^4\,w\,b\,s-2\,g\,c^2\,y^2\,w\,b^3\,G^2-16\,g\,b^2\,G\,c^2\,y^2\,C-24\,g\,b^3\,G^2\,C\,c\,y\\
&-9\,g\,b^3\,s\,c^2\,y^2\,G^2-7\,g\,b^2\,s\,c^3\,y^3\,G+12\,g\,b^2\,s\,c^2\,y^2\,C+8\,g\,c\,y\,b^3\,G\,C-5\,g\,s\,b^4\,G^3\,c\,y\\
&+8\,c\,x\,a\,b^2\,G^2\,C-8\,c\,x\,s\,C\,b^3\,G^2-4\,c^2\,x\,a\,b^2\,G^3\,y-5\,c^3\,x\,a\,b\,G^2\,y^2+4\,c^3\,x\,b\,G\,y^2\,C\\
&+12\,c^2\,x\,b^2\,G^2\,C\,y+5\,c^3\,x\,b^2\,s\,y^2\,G^2+2\,c^4\,x\,b\,s\,y^3\,G-8\,c^3\,x\,b\,s\,y^2\,C+4\,c^2\,x\,s\,b^3\,G^3\,y\\
&-56\,c^2\,x\,b^2\,G\,y\,C-8\,g\,a\,b^3\,G^2\,C-2\,g\,c^4\,y^4\,w\,b-2\,g\,c^4\,y^4\,w\,a-6\,g\,c^2\,y^2\,b^3\,G^2-6\,g\,c^3\,y^3\,b^2\,G\\
&+8\,g\,c^2\,y^2\,b^2\,C+6\,g\,b^4\,G^4\,c\,y+12\,g\,b^3\,G^3\,c^2\,y^2+10\,g\,b^2\,G^2\,c^3\,y^3+3\,g\,b\,G\,c^4\,y^4-2\,g\,b\,s\,c^4\,y^4\\
&+8\,g\,s\,C\,b^4\,G^2-2\,g\,c\,y\,b^4\,G^3-3\,c^2\,x\,b^3\,G^4\,y-2\,c^4\,x\,a\,y^3\,G+8\,c^3\,x\,a\,y^2\,C-3\,c^3\,x\,b^2\,G^3\,y^2\\
&-c^4\,x\,b\,G^2\,y^3+14\,c^2\,x\,b^3\,G^3\,y+16\,c^3\,x\,b^2\,G^2\,y^2+6\,c^4\,x\,b\,G\,y^3-24\,c^3\,x\,y^2\,C\,b-c\,x\,a\,b^3\,G^4\\
&-16\,c\,x\,a\,C^2\,b+8\,c\,x\,b^3\,G^3\,C-16\,c\,x\,b^2\,G\,C^2+16\,c\,x\,s\,C^2\,b^2+c\,x\,s\,b^4\,G^4-32\,c\,x\,b^3\,G^2\,C)\Big/\\
&(4\,g\,b^2\,c^2\,y\,w\,x\,C\,G-2\,g^2\,b\,c^4\,y^4+8\,g^2\,b^4\,G^2\,C-c^2\,x^2\,b^3\,G^4-16\,c^2\,x^2\,b\,C^2-64\,K\,b^3\,G^2\,C\\
&-g^2\,b^5\,G^4-16\,g^2\,b^3\,C^2+16\,K\,c^4\,y^4+8\,K\,b^4\,G^4+128\,K\,C^2\,b^2+20\,g^2\,b^3\,G\,c\,y\,C\\
&-g^2\,b^4\,c\,y\,w\,G^3-4\,g^2\,b^3\,c^2\,y^2\,w\,G^2-5\,g^2\,b^2\,c^3\,y^3\,w\,G+4\,g^2\,b^2\,c^2\,y^2\,w\,C-16\,g\,b^3\,c\,x\,G^2\,C\\
&+9\,g\,b^3\,c^2\,x\,G^3\,y+12\,g\,b^2\,c^3\,x\,G^2\,y^2+5\,g\,b\,c^4\,x\,y^3\,G-20\,g\,b\,c^3\,x\,y^2\,C+8\,c^3\,x^2\,b\,G\,y\,C\\
&-160\,K\,b^2\,G\,c\,y\,C+40\,K\,b^3\,G^3\,c\,y+72\,K\,b^2\,G^2\,c^2\,y^2+56\,K\,b\,G\,c^3\,y^3-96\,K\,c^2\,y^2\,C\,b
\end{aligned}$$

$$\begin{aligned}
&-7\,g^2\,b^2\,G\,c^3\,y^3-9\,g^2\,b^3\,G^2\,c^2\,y^2+12\,g^2\,b^2\,c^2\,y^2\,C-5\,g^2\,b^4\,G^3\,c\,y-2\,g^2\,b\,c^4\,y^4\,w\\
&+2\,g\,b^4\,c\,x\,G^4+32\,g\,b^2\,c\,x\,C^2-2\,c^3\,x^2\,b^2\,G^3\,y-c^4\,x^2\,b\,G^2\,y^2+8\,c^2\,x^2\,b^2\,G^2\,C\\
&+4\,g^2\,b^3\,c\,y\,w\,C\,G-36\,g\,b^2\,c^2\,x\,G\,y\,C-g\,b^3\,c^2\,y\,w\,x\,G^3+4\,g\,b\,c^3\,y^2\,w\,x\,C-2\,g\,b^2\,c^3\,y^2\,w\,x\,G^2\\
&-g\,b\,c^4\,y^3\,w\,x\,G)\,g\,c^2\,y^2\big)
\end{aligned}$$

Appendix 4: Ethics Form

Ethics Form

Research Title:

Government incentives for the use of green product technology by the supplier and the manufacturer in the green supply chain

Aims of the semi-structured interview:

- To gather practical information on car industry in UK market, car supply chain management, and the government green incentives.
- To identify the parties that may be influenced by government's the green product incentive policy.
- To explore the structure of decision making process in the green car product incentive model.

Description of the research:

The research aims to identify the green product incentive model through a number of interrelated stages. In the first stage, a mathematical game incentive model is used to investigate the incentive influence on supply chain and market. To date, the first stage is completed. I have found that the government incentive has positive influence to supply chain and the green product market. In the second stage, practical information will be collected in order to construct a green product incentive model. Such information is collected through semi-structured interview. In the third stage, an incentive model will be created based on simulation based modeling approach, which contains the government, the supplier, the manufacturer, the distributor, and the retailer (multiple players involved). Simulation will be used to analyse the decision making process in the incentive model. The research aims to contribute to the extant literature by establishing an incentive model on the basis of simulation approach. It also aims to provide managerial insights to the government and supply chain decision managers.

Risks to the participants:

It is believed that this study will incur no physical or psychological harm to its participants. In order minimize potential risks to participants' safety, interviews will be carried out wherever the respondent feel most comfortable – usually the places of their residence or work. All the potential risks will be minimized.

Consent

Consent is given in an oral form. Participants are approached before the interviews. They will be briefed about the research, and thus asked for the consent. Every potential participant is given time to consider and/or question before a final decision of participation is made. An interview is scheduled, only the consent of a participant is given.

Confidentiality and Anonymity

- Audio recording is employed in all interviews.
- The information obtained from this interview will only be used for the purpose of academic research, and no information obtained from this interview will be passed on to a third party. The individuals, firms and organisations involved in this interview will be kept as anonymous.

Data access and Dissemination

Only Yuling Lin, PhD student; and Baris Yalabik, Christos Vasilakis and Paul Goodwin, the research supervisor, have the access to the data. The research report (thesis) will be available at the Library of University of Bath. Conference and seminar papers will be written and published based on this study.

Contact of the researcher

Yuling Lin, PhD student of Management school, University of Bath

yll41@bath.ac.uk

Tel: 0[redacted]

Appendix 5: Interview Guide in Preliminary Study 2

Interview Guide

My name is Yuling Lin from the management school, University of Bath in the U.K., I am studying a PhD research degree in operation management field.

My research has focused on the investigation of the influence of government incentive on supply chain green technology's decisions. A mathematical game model is used to verify the influence of incentive through 3P perspectives which is people, profit and planet. My research project firstly examines the influence of the incentives on the decision of supply chain roles. Also, a simulation model is built on the basis of considering supply chain operations. This incentive model will be supported by practical cases from a semi-structure interview data. Eventually, we will propose the best incentive strategy for government, and the suggestions for supply chain decision making will be provided. All the participants of the interviews will be received a report with research findings.

The interview will be conducted within one hour from the beginning to the end. Interviewers will ask you a list of interview questions regarding the information of supply chin behavior. The questions will be mostly focus on the government incentives and green technology development/innovation (environmental friendly technolgy). No commercial, sensitive, valuable information will be involved in the interview questions. The collected information revealed in the interview will be only used in academic research propose, additional information obtained in the interview will be kept confidential. The names of participants, company/organisation information will remain anonymous.

Organisation:

Name:

Position:

Contact details (tel./email):

Date:

Appendix 6: Interview Questions in Preliminary Study 2

<u>Interview question and prompts (for the Manufacturer):</u>

1. Which is the best seller green car in your company in the past five years?
   P1.Why do you think this model can be the best seller?
   P2.What role do you think government has played when you promote this model?

2. When your company delivery the green car marketing strategy, what factors of the car do you think are more influential for consumer preferences?
   P1. Can you give me an example car model?
   P2. Why do you think these factors can affect consumers' choices?

3. Can you describe how does your company consider/evaluate when developing a new green model?
   P1. Can you give an example?
   P2. What are the issues you consider during the process?
   P3. What are the main reasons stopping/driving your company from/toward green technology innovation?

4. Following the question 3, does government's incentives involve in green car design in your company?
   P1. If yes, can you describe how does government policy affect the car design?
   P2. If no, does tax/emission penalty or any other government policy drives has influence on the car green technology design?

5. What is the key production processes/components that highly relevant to green vehicle's environmental friendly technology?
   P1. Why do you think so? Does your company have any problem accessing these key components?
   P2. Which parts you have described take account most production cost?

6. Which roles in the car supply chain do you think are relatively influential for green

vehicle green technology development?

P1. Why do you think so?

P2. Can you give me an example?

7. Does your company have received any government incentives/funding on green technology development?

   P1. If yes, can you provide an example?

   P2. If no, did your company try to apply, and the reason of failure?

   P3. Do you know any of your upstream or downstream has received the incentives?

8. Follow the previous question, what are the incentives you have received and how did it apply?

   P1. Do you think the government financial support influence your company's green technology innovation? Why do you think so?

   P2. Do you think the incentives affect operation decisions and why?

9. Has your company participated the Taiwanese emission trading and for what reasons?

   P1. If yes, for how long?

   P2. If yes, has your company trade for buying permit or selling?

   P3. If no, do you know any of your upstream/downstream take part in the emission trading?

Interview question and prompts (for the Supplier):

1. Which is the best seller green car in the company you supply in the past five years?

   P1.Why do you think this model can be the best seller?

   P2.What role do you think government has played when you promote this model?

2. When the company you supply delivering the green car marketing strategy, what factors of the car do you think are more influential for consumer preferences?

   P1. Can you give me an example car model?

   P2. Why do you think these factors can affect consumers' choices?

3. Can you describe how does your company consider/evaluate when developing a new green component?

   P1. Can you give an example?

   P2. What are the issues you consider during the process?

   P3. What are the main reasons stopping/driving your company from/toward green technology innovation?

4. Following the question 3, does government's incentives involve in green technology development in your company?

   P1. If yes, can you describe how does government policy affect the car design?

   P2. If no, does tax/emission penalty or any other government policy drives has influence on the car green technology design?

5. What is the key production processes/components that highly relevant to green vehicle's environmental friendly technology?

   P1. Why do you think so? Does your company have any problem accessing these key components?

   P2. Which parts you have described take account most production cost?

6. Which roles in the car supply chain do you think are relatively influential for green vehicle green technology development?

   P1. Why do you think so?

   P2. Can you give me an example?

7. Does your company have received any government incentives/funding on green technology development?

   P1. If yes, can you provide an example?

   P2. If no, did your company try to apply, and the reason of failure?

   P3. Do you know any of your upstream or downstream has received the incentives?

8. Follow the previous question, what are the incentives you have received and how did it apply?

   P1. Do you think the government financial support influence your company's green technology innovation? Why do you think so?

   P2. Do you think the incentives affect operation decisions and why?

9. Has your company participated the Taiwanese emission trading and for what reasons?

   P1. If yes, for how long?

   P2. If yes, has your company trade for buying permit or selling?

   P3. If no, do you know any of your upstream/downstream take part in the emission trading?

Appendix 7: Optimal Solutions of Supplier and Manufacturer in Main Study 3

*Optimal solution for product price: p**

$$p = \left(\left(-6\, b \left(\frac{Cm(1-Gm)\, b\, Tmt}{3} + \frac{Cs(1-Gs)\, b\, Tst}{3} + (Tmt\, \beta + Tst\, \alpha)\, c + a \right) Ctm(1-Gm) + 2 \left(\left(\left(\frac{Tmt\, \beta}{2} + Tst\, \alpha \right) c + a \right) b\, Cm(1-Gm) - \frac{c\, (Cs(1-Gs)\, b\, Tst + (Tmt\, \beta + Tst\, \alpha)\, c + a)\, \beta}{2} \right) (Cm(1-Gm)\, b - c\, \beta) \right) Cts(1-Gs) + (-Cm(1-Gm)\, c\, Tmt\, \alpha + Cs(1-Gs)\, (Tmt\, \beta\, c + a))\, (Cs(1-Gs)\, b - c\, \alpha)\, b\, Ctm(1-Gm) \right) \Big/ \left(2 \left(\left(-4\, Ctm(1-Gm)\, b + (Cm(1-Gm)\, b - c\, \beta)^2 \right) Cts(1-Gs) + \frac{Ctm(1-Gm)\, (Cs(1-Gs)\, b - c\, \alpha)^2}{2} \right) b \right)$$

*Optimal solution for wholesale price: w**

$$w = \left(\left(-4\, Ctm(1-Gm)\, b + (Cm(1-Gm)\, b - c\, \beta)^2 \right) (-Cm(1-Gm)\, b\, Tmt + Cs(1-Gs)\, b\, Tst + (Tmt\, \beta + Tst\, \alpha)\, c + a)\, Cts(1-Gs) + Cs(1-Gs)\, Ctm(1-Gm)\, b\, (Cs(1-Gs)\, b - c\, \alpha)\, (-Cm(1-Gm)\, b\, Tmt + c\, Tmt\, \beta + a) \right) \Big/ \left(2 \left(\left(-4\, Ctm(1-Gm)\, b + (Cm(1-Gm)\, b - c\, \beta)^2 \right) Cts(1-Gs) + \frac{Ctm(1-Gm)\, (Cs(1-Gs)\, b - c\, \alpha)^2}{2} \right) b \right)$$

Optimal solution for supplier's green technology level: $T_{s_t}{}^{*}$

$$Ts = -\big(Ctm(1-Gm)\, Cs(1-Gs)\, Cm(1-Gm)\, Tmt\, b^2 - Ctm(1-Gm)\, Cs(1-Gs)\, Tmt\, b\, \beta\, c - Ctm(1-Gm)\, Cm(1-Gm)\, Tmt\, \alpha\, b\, c + Ctm(1-Gm)\, Tmt\, \alpha\, \beta\, c^2 - 2\, Cts(1-Gs)\, Cm(1-Gm)^2\, Tst\, b^2 + 4\, Cts(1-Gs)\, Cm(1-Gm)\, Tst\, b\, \beta\, c - 2\, Cts(1-Gs)\, Tst\, \beta^2\, c^2 - Ctm(1-Gm)\, Cs(1-Gs)\, a\, b + 8\, Ctm(1-Gm)\, Cts(1-Gs)\, Tst\, b + Ctm(1-Gm)\, a\, \alpha\, c \big) \Big/ \big(Ctm(1-Gm)\, Cs(1-Gs)^2\, b^2 - 2\, Ctm(1-Gm)\, Cs(1-Gs)\, \alpha\, b\, c + Ctm(1-Gm)\, \alpha^2\, c^2 + 2\, Cts(1-Gs)\, Cm(1-Gm)^2\, b^2 - 4\, Cts(1-Gs)\, Cm(1-Gm)\, b\, \beta\, c + 2\, Cts(1-Gs)\, \beta^2\, c^2 - 8\, Ctm(1-Gm)\, Cts(1-Gs)\, b \big)$$

Optimal solution for manufacturer's green technology level: $T_{m_t}^{\ *}$

$$
\begin{aligned}
\mathit{Tm} = \Big(& -\mathit{Cm}(1-\mathit{Gm})^4\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Tmt}\,b^4 - \mathit{Cts}(1-\mathit{Gs})\,\mathit{Tmt}\,\beta^4 c^4 + 4\,\mathit{Ctm}(1-\mathit{Gm})^2\,\mathit{Cs}(1-\mathit{Gs})^2\,\mathit{Tmt}\,b^3 - \mathit{Cm}(1 \\
& -\mathit{Gm})^3\,\mathit{Cts}(1-\mathit{Gs})\,a\,b^3 + \mathit{Cts}(1-\mathit{Gs})\,a\,\beta^3 c^3 - 32\,\mathit{Ctm}(1-\mathit{Gm})^2\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Tmt}\,b^2 + \mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cs}(1 \\
& -\mathit{Gs})\,\mathit{Cm}(1-\mathit{Gm})\,a\,\alpha\,b^2 c + 4\,\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cs}(1-\mathit{Gs})\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Tst}\,b^2\beta\,c - \mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cs}(1 \\
& -\mathit{Gs})\,a\,\alpha\,b\,\beta\,c^2 - 24\,\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cm}(1-\mathit{Gm})\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Tmt}\,b^2\beta\,c + 8\,\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cm}(1-\mathit{Gm})\,\mathit{Cts}(1 \\
& -\mathit{Gs})\,\mathit{Ts}\,\alpha\,b^2 c - 4\,\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cm}(1-\mathit{Gm})\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Tst}\,\alpha\,b^2 c - 8\,\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Ts}\,\alpha\,b\,\beta\,c^2 \\
& + 4\,\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Tst}\,\alpha\,b\,\beta\,c^2 + 2\,\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cs}(1-\mathit{Gs})^2\,\mathit{Cm}(1-\mathit{Gm})\,\mathit{Tmt}\,b^3\beta\,c - \mathit{Ctm}(1 \\
& -\mathit{Gm})\,\mathit{Cs}(1-\mathit{Gs})^2\,\mathit{Cm}(1-\mathit{Gm})\,\mathit{Ts}\,\alpha\,b^3 c + \mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cs}(1-\mathit{Gs})^2\,\mathit{Ts}\,\alpha\,b^2\beta\,c^2 + \mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cs}(1 \\
& -\mathit{Gs})\,\mathit{Cm}(1-\mathit{Gm})^2\,\mathit{Tmt}\,\alpha\,b^3 c + 2\,\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cs}(1-\mathit{Gs})\,\mathit{Cm}(1-\mathit{Gm})\,\mathit{Ts}\,\alpha^2 b^2 c^2 + \mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cs}(1 \\
& -\mathit{Gs})\,\mathit{Tmt}\,\alpha\,b\,\beta^2 c^3 - 2\,\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cs}(1-\mathit{Gs})\,\mathit{Ts}\,\alpha^2 b\,\beta\,c^3 - 3\,\mathit{Cs}(1-\mathit{Gs})\,\mathit{Cm}(1-\mathit{Gm})^2\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Tst}\,b^3\beta\,c \\
& + 3\,\mathit{Cs}(1-\mathit{Gs})\,\mathit{Cm}(1-\mathit{Gm})\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Tst}\,b^2\beta^2 c^2 + 6\,\mathit{Cm}(1-\mathit{Gm})^2\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Ts}\,\alpha\,b^2\beta\,c^2 - 3\,\mathit{Cm}(1 \\
& -\mathit{Gm})^2\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Tst}\,\alpha\,b^2\beta\,c^2 - 6\,\mathit{Cm}(1-\mathit{Gm})\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Ts}\,\alpha\,b\,\beta^2 c^3 + 3\,\mathit{Cm}(1-\mathit{Gm})\,\mathit{Cts}(1 \\
& -\mathit{Gs})\,\mathit{Tst}\,\alpha\,b\,\beta^2 c^3 - \mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cs}(1-\mathit{Gs})^2\,\mathit{Tmt}\,b^2\beta^2 c^2 - \mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cm}(1-\mathit{Gm})\,\mathit{Ts}\,\alpha^3 b\,c^3 - \mathit{Cs}(1 \\
& -\mathit{Gs})\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Tst}\,b\,\beta^3 c^3 + 4\,\mathit{Cm}(1-\mathit{Gm})^3\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Tmt}\,b^3\beta\,c - 2\,\mathit{Cm}(1-\mathit{Gm})^3\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Ts}\,\alpha\,b^3 c \\
& + \mathit{Cm}(1-\mathit{Gm})^3\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Tst}\,\alpha\,b^3 c - 6\,\mathit{Cm}(1-\mathit{Gm})^2\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Tmt}\,b^2\beta^2 c^2 + 4\,\mathit{Cm}(1-\mathit{Gm})\,\mathit{Cts}(1 \\
& -\mathit{Gs})\,\mathit{Tmt}\,b\,\beta^3 c^3 - 8\,\mathit{Ctm}(1-\mathit{Gm})^2\,\mathit{Cs}(1-\mathit{Gs})\,\mathit{Tmt}\,\alpha\,b^2 c - 4\,\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cs}(1-\mathit{Gs})\,\mathit{Cm}(1-\mathit{Gm})\,\mathit{Cts}(1 \\
& -\mathit{Gs})\,\mathit{Tst}\,b^3 - \mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cm}(1-\mathit{Gm})\,a\,\alpha^2 b\,c^2 + 12\,\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Tmt}\,b\,\beta^2 c^2 + 3\,\mathit{Cm}(1 \\
& -\mathit{Gm})^2\,\mathit{Cts}(1-\mathit{Gs})\,a\,b^2\beta\,c - 3\,\mathit{Cm}(1-\mathit{Gm})\,\mathit{Cts}(1-\mathit{Gs})\,a\,b\,\beta^2 c^2 - 4\,\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cts}(1-\mathit{Gs})\,a\,b\,\beta\,c \\
& - 2\,\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cs}(1-\mathit{Gs})\,\mathit{Cm}(1-\mathit{Gm})\,\mathit{Tmt}\,\alpha\,b^2\beta\,c^2 + 4\,\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cm}(1-\mathit{Gm})\,\mathit{Cts}(1-\mathit{Gs})\,a\,b^2 \\
& - \mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cs}(1-\mathit{Gs})^2\,\mathit{Cm}(1-\mathit{Gm})^2\,\mathit{Tmt}\,b^4 + \mathit{Ctm}(1-\mathit{Gm})\,\mathit{Ts}\,\alpha^3\beta\,c^4 + \mathit{Cs}(1-\mathit{Gs})\,\mathit{Cm}(1-\mathit{Gm})^3\,\mathit{Cts}(1 \\
& -\mathit{Gs})\,\mathit{Tst}\,b^4 + 2\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Ts}\,\alpha\,\beta^3 c^4 - \mathit{Cts}(1-\mathit{Gs})\,\mathit{Tst}\,\alpha\,\beta^3 c^4 + 4\,\mathit{Ctm}(1-\mathit{Gm})^2\,\mathit{Tmt}\,\alpha^2 b\,c^2 + 12\,\mathit{Ctm}(1 \\
& -\mathit{Gm})\,\mathit{Cm}(1-\mathit{Gm})^2\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Tmt}\,b^3 + \mathit{Ctm}(1-\mathit{Gm})\,a\,\alpha^2\beta\,c^3\Big) \Big/ \Big(\Big(-\mathit{Cm}(1-\mathit{Gm})^2 b^2 + 2\,\mathit{Cm}(1-\mathit{Gm})\,b\,\beta\,c \\
& -\beta^2 c^2 + 4\,\mathit{Ctm}(1-\mathit{Gm})\,b\Big)\Big(\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cs}(1-\mathit{Gs})^2 b^2 - 2\,\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cs}(1-\mathit{Gs})\,\alpha\,b\,c + \mathit{Ctm}(1 \\
& -\mathit{Gm})\,\alpha^2 c^2 + 2\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Cm}(1-\mathit{Gm})^2 b^2 - 4\,\mathit{Cts}(1-\mathit{Gs})\,\mathit{Cm}(1-\mathit{Gm})\,b\,\beta\,c + 2\,\mathit{Cts}(1-\mathit{Gs})\,\beta^2 c^2 \\
& - 8\,\mathit{Ctm}(1-\mathit{Gm})\,\mathit{Cts}(1-\mathit{Gs})\,b\Big)\Big)
\end{aligned}
$$